International Conference on

Mesoscopic Superconductivity and Magnetism

MesoSuperMag - 2006

Chicago, Illinois

August 28th – September 1st, 2006

Abstract Book

International Coordinators

Wai-Kwong Kwok, ANL (USA)
George W. Crabtree, ANL (USA)
Boldizsar Janko, Notre Dame (USA)
Kazuo Kadowaki, Tsukuba (Japan)
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International Conference on Mesoscopic Superconductivity and Magnetism -2006

Venue Information Sheet

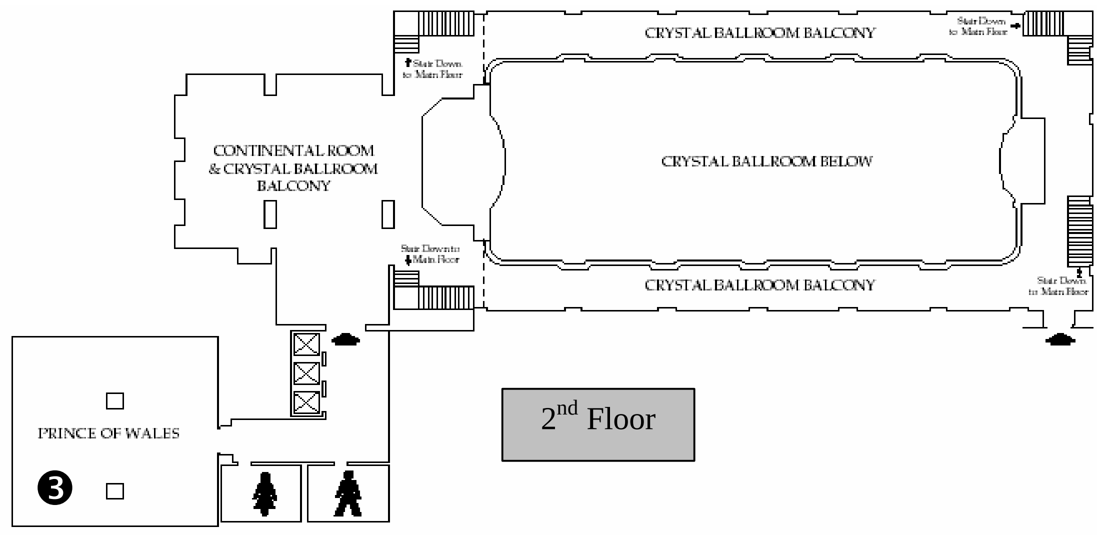
International Conference on Mesoscopic Superconductivity and Magnetism -2006

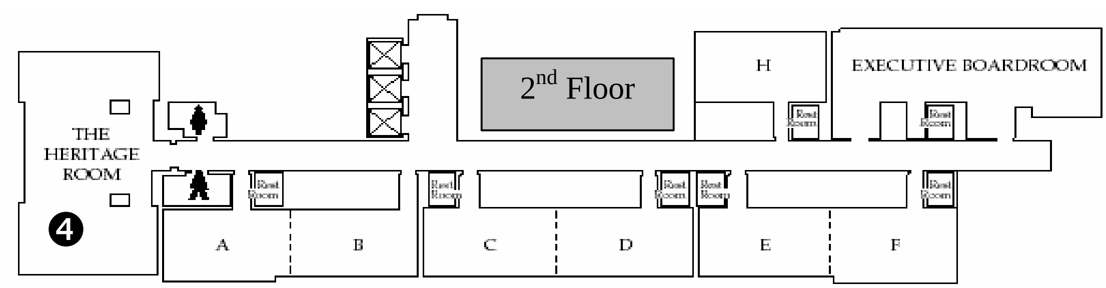
❶ Continental Breakfast – Tower West Promenade, 14th floor

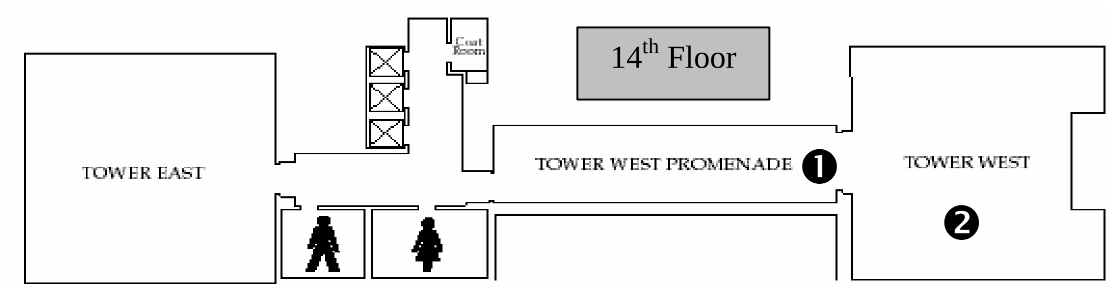
❷ All talks are in the Towers West Room, 14th floor

❸ All lunches will be in the Prince of Whales room on the 2nd floor

❹ Poster Session, 2nd floor







	Tues. August 29th	Wed. August 30th	Thu. August 31st	Fri. September 1st
7:45- 8:30	Continental Breakfast	Continental Breakfast	Continental Breakfast	Continental Breakfast
8:30-8:50	**Opening** **Field effect & Q-bits** **Chair: G. Crabtree**	**Hybrids: Magnetic Coupling** **Chair: K. Kadowaki** *G. Karapetrov*	**THz- Emission** **Chair: A. Koshelev** *M. Tachiki*	**Vortex motion: Theory** **Chair: W. Kwok** *S. Teitel*
8:50-9:10	*A. Goldman*	*V. Moshchalkov*	*L. Bulaevskii*	*X. Hu*
9:10-9:30	*P. Martinoli*	*A. Zhukov*	*H. Wang*	*G. Zimanyi*
9:30-9:50	*N. Pavlenko*	*I. Lyuksyutov*	*C. Otani*	*C. Olson- Reichhardt*
9:50-10:10	*F. Nori*	*J. Santamaria*	*S. Savel'ev*	*K. Tanaka*
10:10-10:30	*S. Valenzuela*	*V. Metlushko*	Coffee Break	Coffee Break
10:30-10:50	Coffee Break	*B. Janko*	**Quantum transport** **Chair: D. van Harlingen** *A. Bezryadin*	**Vortex pinning, matching** **Chair: G. Zimanyi** *C. Reichhardt*
10:50-11:10	**Junctions & Proximity** **Chair: V. Moshchalkov** *V. Chandrasekhar*	Coffee Break	*M. Tian*	*Z. Xiao*
11:10-11:30	*D. van Harlingen*	**Josephson vortices** **Chair: M. Tachiki** *A. Koshelev*	*C. Petrovic*	*A. Silhanek*
11:30-11:50	*L. Greene*	*T. Hatano*	*J. Haruyama*	*T. Nishizaki*
11:50-12:10	*S. Takahashi*	*I. Kakeya*	*R. Jin*	*J. Vicent*
12:10-12:30	*H. Hilgenkamp*	*M. Machida*	*I. Beloborodov*	Lunch
12:30-12:50	*M. Eschrig*	*Y. Kubo*	*T. Koyama*	
12:50-1:10	*H. Takayanagi*	Lunch	Lunch	
1:10-2:00	Lunch			
2:00-4:00	Free time	Excursion (2:00 – 4:50)	Free time	Free time
4:00-4:30	Coffee Break		Coffee Break	Coffee Break
4:30-4:50	**Imaging** **Chair: M. Iavarone** *I. Grigorieva*		**Materials** **Chair: Z. Xiao** *J. Sarrao*	**Vortices in Mesosc. Superconductors** **Chair: U. Welp** *A. Rydh*
4:50-5:10	*M. Eskildsen*	***Poster session & Break*** ***(Heritage Room – 2nd floor)***	*U. Welp*	*F. Peeters*
5:10-5:30	*T. Hanaguri*		*K Kadowaki*	*A. Kanda*
5:30-5:50	*T. Tamegai*		*L. Civale*	*M. Miloševic*
5:50-6:10	*V. Vlasko-Vlasov*		*A. Bhattacharya*	*M. Kato*
6:10-6:30				
6:30-6:50				
7:00				
7:30			Banquet	

Scientific Program – Oral Presentations

International Conference on Mesoscopic Superconductivity and Magnetism -2006

Monday evening - August 28, 2006

Registration: 3-6 PM – Millennium Knickerbocker Hotel - Lobby

Tuesday, August 29, 2006

Registration: 7-11 AM, Promenade, 14th floor

07:45 – 8:30 AM	Continental Breakfast – Promenade, 14th floor
8:30 – 10:30 AM	**Field Effect and Q-bits** – Tower West Room, 14th floor Chair: George Crabtree, Argonne National Laboratory, USA
08:30 - 08:50	Opening remarks
08:50 - 09:10	Allen Goldman, University of Minnesota, USA The control of superconductivity using the electric field effect
09:10 - 09:30	Piero Martinoli, Universite de Neuchatel, Switzerland Probing the superfluid properties of ultrathin copper-oxide superconducting films with the electric field effect
09:30 - 09:50	Natalia Pavlenko, University of Augsburg, Germany Interface hole-doping in cuprate-titanate heterostructures: Consequences for superconducting field effect
09:50 - 10:10	Franco Nori, University of Michigan & RIKEN, Japan Superconducting qubits
10:10 - 10:30	Sergio Valenzuela, MIT, USA Dynamics of a strongly driven superconducting qubit
10:30 – 10:50 AM	Coffee Break – Promenade Area, 14th floor
10:50 AM – 1:10 PM	**Superconducting Junctions & Proximity Effect** – Tower West Room, 14th floor Chair: Kazuo Kadowaki, University of Tsukuba, Japan
10:50 - 11:10	Venkat Chandrasekhar, Northwestern University, USA Crossed Andreev reflection, elastic co-tunneling and charge imbalance: Non-local effects in normal-superconducting systems
11:10 - 11:30	Dale J. Van Harlingen, Univ. of Illinois at Urbana-Champaign, USA Current-phase relations and spontaneous currents in superconductor-ferromagnet-superconductor π-Josephson junctions and arrays

11:30 - 11:50	Laura Greene, Univ. of Illinois at Urbana-Champaign, USA Andreev reflection spectroscopy of the pure and Cd-doped heavy Fermion superconductor $CeCoIn_5$: detecting order parameter symmetry and competing phases
11:50 - 12:10	Saburo Takahashi, Tohoku University, Japan Josephson current through a strong ferromagnet
12:10 - 12:30	Hans Hilgenkamp, University of Twente, Netherlands Experiments with fractional flux quanta
12:30 - 12:50	Matthias Eschrig, Universitaet Karlsruhe, Germany Unconventional proximity effects in superconductor-ferromagnet hybrids
12:50 - 1:10	Hideaki Takayanagi, Tokyo University of Science, Japan Transport properties of ferromagnetic semiconductors with superconducting electrodes
1:10 – 2:00 PM	Lunch – Prince of Wales Room, Mezzanine level (Buffet)
2:00 – 4:00 PM	Free time
4:00 – 4:30 PM	Coffee Break – Promenade Area, 14^{th} floor
4:30 – 6:10 PM	**Imaging of Superconductors** – Tower West Room, 14^{th} floor Chair: Maria Iavarone, Argonne National Laboratory, USA
4:30 - 4:50	Irina Grigorieva, University of Manchester, UK Vortex configurations in mesoscopic superconductors: direct observation using Bitter decoration
4:50 - 5:10	Morten Eskildsen, University of Notre Dame, USA Indications of a field dependence vortex core size in $CeCoIn_5$
5:10 - 5:30	Tetsuo Hanaguri, RIKEN, Japan Electronic “checkerboard” and superconductivity in $Ca_{2-x}Na_xCuO_2Cl_2$
5:30 - 5:50	Tsuyoshi Tamegai, University of Tokyo, Japan Magneto-optical imaging and colossal magnetoresistance in manganites
5:50 - 6:10	Vitalii Vlasko-Vlasov, Argonne National Laboratory, USA Imaging transport currents and I-V curves in second generation coated conductors
6:10 PM	Adjourn for the evening

Wednesday, August 30, 2006

07:45 – 08:30 AM	Continental Breakfast – Promenade, 14^{th} floor
08:30 – 10:50 AM	**Hybrids, Nanostructures and Thin Films** – Tower West Room, 14^{th} floor Chair: Ulrich Welp, Argonne National Laboratory, USA
08:30 - 08:50	Goran Karapetrov, Argonne National Laboratory, USA STM in mesoscopic single crystal superconductors
08:50 - 09:10	Victor V. Moshchalkov, Katholieke Universiteit Leuven, Belgium Vortex manipulation and ratchets in nanostructured superconductors and superconductor/ferromagnet hybrids
09:10 - 09:30	Alexander Zhukov, University of Southampton, UK Superconducting and magnetic vortices in periodical arrays with spheroidal shape of nano-elements
09:30 - 09:50	Igor Lyuksyutov, Texas A & M University, USA Magnetic nanowires/superconductor systems
09:50 - 10:10	Jacobo Santamaria, Universidad Complutense de Madrid, Spain Interplay between ferromagnetism and superconductivity in cuprate / manganite structures
10:10 - 10:30	Vitalii Metlushko, University of Illinois - Chicago, USA Vortex Chirality
10:30 - 10:50	Boldizsar Janko, University of Notre Dame, USA Manipulation of spin and charge in magnetic semiconductor hybrids
10:50 – 11:10 AM	Coffee Break – Promenade Area, 14^{th} floor
11:10 AM – 1:10 PM	**Josephson Vortices** – Tower West Room, 14^{th} floor Chair: Masashi Tachiki, University of Tokyo, Japan
11:10 - 11:30	Alexei Koshelev, Argonne National Laboratory, USA Ground states of Josephson vortex lattice in layered superconductors at different magnetic fields and temperatures
11:30 - 11:50	Takeshi Hatano, National Inst. for Materials Science, Japan Lock-in phenomena of Josephson vortices in intrinsic Josephson junctions
11:50 - 12:10	Itsuhiro Kakeya, University of Tsukuba, Japan Various vortex states in the vicinity of the *ab*-plane of $Bi_2Sr_2CaCu_2O_{8+\delta}$ probed by the *c*-axis resistivity of mesoscopic crystals
12:10 – 12:30	Masahiko Machida, CCSE, Japan Atomic Energy Agency, Japan Confinement effects of Josephson vortices in layered cuprate high-T_c superconductors
12:30 - 12:50	Yuimaro Kubo, University of Tsukuba, Japan Magnetic field dependence of the lock-in transition in $Bi_2Sr_2CaCuO_{8+\delta}$ mesoscopic single crystals

1:10 – 2:00 PM	Lunch – Prince of Wales Room, Mezzanine level (Buffet)
2:00 – 4:50 PM	Excursion Chicago's First Lady Architectural Boat Tour - 3 pm; $25/pp; departs from Michigan Ave at Wacker Drive – (arrive 20 min prior to departure)
4:50 – 7:00 PM	Poster Session – Heritage Room (2nd floor)
7:00 PM	Adjourn for the evening

Thursday, August 31, 2006

07:45 – 08:30 AM	Continental Breakfast – Promenade, 14th floor
08:30 – 10:10 AM	**Josephson Vortex Dynamics** – Tower West Room, 14th floor Chair: Alexei Koshelev, Argonne National Laboratory
08:30 - 08:50	Masashi Tachiki, University of Tokyo, Japan Emission of terahertz waves through resonance excitation of Josephson plasma by moving Josephson vortices
08:50 - 09:10	Lev Bulaevskii, Los Alamos National Laboratory, USA Radiation from Josephson oscillations in artificial and intrinsic tunneling junction structures
09:10 - 09:30	Huabing Wang, National Inst. for Materials Science, Japan Josephson vortex dynamics and THz oscillation in sub-micron intrinsic Josephson junctions
09:30 - 09:50	Chiko Otani, RIKEN, Japan Development of terahertz imaging detector using superconducting tunnel junctions
09:50 - 10:10	Sergey Savel'ev, RIKEN, Japan Controlling terahertz radiation, critical currents density, and IV characteristics in nano-fabricated superconductors
10:10 – 10:30 AM	Coffee Break – Promenade Area, 14th floor
10:30 AM – 12:50 PM	**Quantum Transport** – Tower West Room, 14th floor Chair: Dale J. Van Harlingen, Univ. of Illinois at Urbana-Champaign
10:30 - 10:50	Alexey Bezryadin, Univ. of Illinois at Urbana-Champaign, USA Superconducting nanowires
10:50 - 11:10	Mingliang Tian, Penn State University, USA Suppression of superconductivity in zinc nanowires by bulk superconductors
11:10 - 11:30	Cedomir Petrovic, Brookhaven National Laboratory, USA Superconductivity and electrical transport properties in quasi-one dimensional conductor Nb_2Se_3
11:30 - 11:50	Junji Haruyama, Aoyama Gakuin University, Japan Superconductivity in entirely end-bonded carbon nanotubes
11:50 - 12:10	Rongying Jin, Oak Ridge National Laboratory, USA Superconducting properties of $NbSe_2$ nanowires
12:10 - 12:30	Igor Beloborodov, Argonne National Laboratory, USA Superconductive nanosolids
12:30 - 12:50	Tomio Koyama, Tohoku University, Japan Theory for macroscopic quantum tunneling in a stack of capacitively-coupled intrinsic Josephson junctions
12:50– 2:00 PM	Lunch – Prince of Wales Room, Mezzanine level (Buffet)

2:00 – 4:00 PM	Free time
4:00 – 4:30 PM	Coffee Break – outside Continental Room – Mezzanine level
4:30 – 6:10 PM	**Novel Materials** – Tower West Room, 14th floor Chair: Zhili Xiao, Argonne National Laboratory, USA
4:30 - 4:50	John Sarrao, Los Alamos National Laboratory, USA Tuning unconventional f-electron superconductors
4:50 - 5:10	Ulrich Welp, Argonne National Laboratory, USA Anisotropic superconducting phase diagram and isotopic effect of C_6Ca
5:10 - 5:30	Kazuo Kadowaki, University of Tsukuba, Japan Superconductivity in graphite intercalation compound C_6Ca
5:30 - 5:50	Leonardo Civale, Los Alamos National Laboratory, USA Understanding and pushing the limits of vortex pinning in $YBa_2Cu_3O_{7-\delta}$ based coated conductors
5:50 - 6:10	Anand Bhattacharya, Argonne National Laboratory, USA Digital synthesis of manganites: an example of emergent phases at ordered interfaces
7:30 PM	**Banquet** – Lakefront Room RIVA (located at Navy Pier) 700 E. Grand Avenue Chicago, IL 60611

Friday, September 1, 2006

07:45 – 08:30 AM	Continental Breakfast – Promenade, 14th floor
08:30 – 10:10 AM	**Vortex Dynamics: Theory** – Tower West Room, 14th floor Chair: Wai Kwok, Argonne National Laboratory, USA
8:30 - 8:50	Stephen Teitel, University of Rochester, USA Vortex line ordering in the driven three-dimensional vortex glass
8:50 - 9:10	Xiao Hu, National Inst. for Materials Science, Japan Creep phenomena of current driven vortices
9:10 - 9:30	Gergely Zimanyi, Univeristy of California, Davis, USA Vortex glasses with different underlying symmetries and the dynamics of vortex channel flow
9:30 - 9:50	Cynthia Olson-Reichhardt, Los Alamos National Laboratory, USA Local vortex probes: entanglement, melting, and reordering transitions
9:50 - 10:10	Kaori Tanaka, University of Saskatchewan, Canada Theory of vortices in hybridized ballistic/diffusive-band superconductors
10:10 – 10:30 AM	Coffee Break – Promenade Area, 14th floor
10:30 AM – 12:10 PM	**Vortex Pinning and Matching Effects**– West Tower Room, 14th floor Chair: Gergely Zimanyi, University of California, Davis, USA
10:30 - 10:50	Charles Reichhardt, Los Alamos National Laboratory, USA Novel vortex configurations in elongated pinning sites
10:50 - 11:10	Zhili Xiao, Argonne National Laboratory, USA Origin of the matching effect in superconducting films containing arrays of holes
11:10 - 11:30	Alejandor Silhanek, Katholieke Universiteit Leuven, Belgium Flux pinning controlled by artificial microstructures in conventional superconducting films
11:30 - 11:50	Terukazu Nishizaki, Tohoku University, Japan In-Plane anisotropy of vortex motion and electronic state of the CuO chain in $YBa_2Cu_3O_y$
11:50 - 12:10	Jose Luis Vicent, Universidad Complutense, Spain Proximity and ratchet effects in mesoscopic superconducting/magnetic systems
12:10 – 2:00 PM	Lunch – Prince of Wales Room, Mezzanine level (Buffet)
2:00 – 4:00 PM	Free time
4:00 – 4:30 PM	Coffee Break – Promenade Area, 14th floor

4:30 – 6:30 PM **Vortices in Mesoscopic Superconductors** – Tower West Room, 14th floor, Chair: Victor Moshchalkov, Katholieke Universiteit Leuven, Belgium

4:30 - 4:50 Milorad Milosevic, Universiteit Antwerpen, Belgium
Novel vortex phenomena in three-dimensional superconductor-ferromagnet hybrids

4:50 - 5:10 Francois Peeters, Universiteit Antwerpen, Belgium
Vortex matter in superconducting films with a square array of anti-dots

5:10 - 5:30 Akinobu Kanda, University of Tsukuba, Japan
Quasi-one-dimensional vortex in mesoscopic superconducting rings

5:30 - 5:50 Andreas Rydh, University of Stockholm, Sweden
Hall micro-probe study of a few-fluxoid lead crystal

5:50 - 6:10 Masaru Kato, Osaka Prefecture University, Japan
Basic properties and applications of composite structures of d- and s-wave superconductors; d-dot

Scientific Program – Poster Presentations

International Conference on Mesoscopic Superconductivity and Magnetism -2006

P1 Effect of Columnar Disorder on the Vortex Matter Phase Diagram in Untwinned $YBa_2Cu_3O_y$ - Terukazu Nishizaki, Kuniaki Kasuga, Satoru Okayasu, and Norio Kobayashi

P2 Scanning Tunneling Microscopy/Spectroscopy on Superconducting Boron-Doped Diamond - Terukazu Nishizaki, Yoshihiko Takano, Masanori Nagao, Tomohiro Takenouchi, Hiroshi Kawarada3, and Norio Kobayashi

P3 Magnetic Resonance Studies on $RuSr_2GdCu_2O_8$ - John M. Densmore, Morten R. Eskildsen, and Christian Bernhard

P4 Magnetic Field Dependence of the Lock-in Transition in $Bi_2Sr_2CaCu_2O_{8+d}$ Mesoscopic Single Crystals - Y. Kubo, I. Kakeya, M. Kohri, K. Kawamata, T. Yamamoto, and K. Kadowaki

P5 Superconducting Qubits - Franco Nori, Y. X. Liu, L. F. Wei, and J. Q. You

P6 Magnetic and Mechanical Buckling: Moified Landau Theory Approach to Study Phase Transitions in Micro-magnetic Disks and Compressed Rods - Sergey Savel'ev and Franco Nori

P7 Controlling the Motion of Tiny Particles and Magnetic Flux Quanta - Sergey Savel’ev and Franco Nori

P8 Surface THz Plasma Waves and THz Detectors - Sergey Savel’ev, V. A. Yampol’skii, and Franco Nori

P9 THz Radiation Generation and Control Using Superconductors - Sergey Savel’ev, V. A. Yampol’skii, A. L. Rakhmanov, and Franco Nori

P10 Enhancing critical Currents in Superconductors with Quasiperiodic Pinning Arrays: Chains and Two-dimensional Penrose Lattices – Vyacheslav R. Misko, Sergey Savel’ev, and Franco Nori

P11 Thermodynamic Phase Diagram of Interlayer Josephson Vortices – Xiao Hu

P12 Fabricating superconducting nanostructures using anodic aluminum oxide: a versatile template approach - Z. L. Xiao*, C. Y. Han, H. H. Wang, U. Welp, R. E. Cook, G. A. Willing, D. J. Miller, W. K. Kwok, and G. W. Crabtree

P13 3D Mesoscopic Superconductors with Controlled Shapes - Z. L. Xiao, C. Y. Han, H. H. Wang, U. Welp, J. Wang, W. K. Kwok, and G. W. Crabtree

P14 Phase diagram difference in ion-irradiated YBCO by heat capacity measurements - R. Xie, A. Rydh, U. Welp, W. K. Kwok, M. Eskildsen, and L. Paulius

P15 Report of the Basic Energy Sciences (BES) Workshop on BASIC RESEARH NEEDS FOR SUPERCONDUCTIVITY

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Mesoscopic Superconductivity and Magnetism

MesoSuperMag - 2006

Abstracts of Oral Presentations

The Control of Superconductivity Using the Electric Field Effect

A. M. Goldman

School of Physics and Astronomy, University of Minnesota

We have been investigating the properties of ultrathin films of metals and cuprates grown on high dielectric constant substrates, which also serve as the gate insulators of field effect devices. In the case of metal films we have been able to reversibly alter the ground state from insulating to superconducting at the same time as changing the mode of conduction from strong to weak localization. These same films can be driven back into the insulating state by the application of parallel magnetic fields. Finite size scaling analyses (temperature scaling) can be carried out for both transitions with the same exponent products. The previously reported intermediate metallic regime separating superconducting and insulating regimes appears to be a hot electron effect resulting from the failure of the electrons to cool in the presence of even a small measuring current. This conclusion was reached by noting that the temperature at which the resistance becomes independent of temperature can be moved to higher temperatures by increasing the bias current. Based on this observation and using the film resistance as a thermometer, a relationship between power dissipated in the film and effective electron temperature can be found. This relationship makes it possible to map electric field (or in-plane voltage) scaling directly onto temperature scaling by relating the measured voltages to elevated electron temperatures. This provides a consistency argument for the temperature independent behavior being due to the failure of electrons to cool.

Work performed in collaboration with K. Parendo and K. H. Sarwa B. Tan, and supported by the National Science Foundation.

Probing the superfluid properties of ultrathin copper-oxide superconducting films with the electric-field effect

Piero Martinoli[1], Alain Rüfenacht[1], Jean-Pierre Locquet[2], Jean Fompeyrine[2], Daniele Caimi[2]

[1]Institut de Physique, Université de Neuchâtel, CH-2000 Neuchâtel, Switzerland,
[2]IBM Research Division, Zurich Research Laboratory, CH-8803 Rüschlikon, Switzerland

An elegant way to investigate the doping dependence of various properties of copper-oxide superconductors relies on the electric-field effect, which allows to modulate the free-carrier concentration of a *single* sample and is therefore exempt from the uncertainties associated with sample-to-sample varying disorder of other experimental approaches. So far, tunable electric-field-effect devices incorporating a copper-oxide superconductor were almost exclusively studied with conventional transport measurements probing the resitive region above the critical temperature T_c. A powerful method to investigate the superconducting state of thin films below T_c is to measure their temperature-dependent sheet kinetic inductance $L_k(T)$, a quantity which is inversely proportional to their areal superfluid density n_s. By capacitively charging MBE grown ultrathin (1-2 unit-cell-thick) $La_{2-x}Sr_xCuO_4$ films [1] with an electric field E applied across a gate insulator (HfO_2) with a high dielectric constant, relative electrostatic modulations $\Delta n_s/n_s \sim 10\%$ were observed [2] for E-fields of the order of 10^8 V/m in L_k measurements performed with a mutual inductance technique [3]. Although n_s appears to be substantially reduced by disorder, in the underdoped regime ($x = 0.1$) the data provide, for the first time on the same sample [2], direct compelling evidence for the Uemura relation $T_c \propto n_s(T = 0)$ [4] of copper-oxide superconductors. When adequately normalized, $n_s(T, E)$ exhibits a universal temperature dependence, which, at low temperatures, follows the theoretical prediction for disordered d-wave superconductors [5]. Combined with Uemura's relation and a simple model for the electrostatic behavior of the superconductor-insulator interface, the universal temperature scaling provides an accurate description of the changes of n_s with temperature and electric field.

[1] A. Rüfenacht, P. Chappatte, S. Gariglio, Ch. Leemann, J. Fompeyrine, J.-P. Locquet, and P. Martinoli, Solid-state Electronics 47, 2167 (2003).
[2] A. Rüfenacht, J.-P. Locquet, J. Fompeyrine, D. Caimi, and P. Martinoli, Phys. Rev. Lett. 96, 227002 (2006).
[3] B. Jeanneret, J.L. Gavilano, G.A. Racine, Ch. Leemann, and P. Martinoli, Appl. Phys. Lett. 55, 2336 (1989).
[4] Y.J. Uemura *et al.*, Phys. Rev. Lett. 62, 2317 (1989).
[5] P.J. Hirschfeld and N.D. Goldenfeld, Phys. Rev. B 48, 4219 (1993).

Interface hole-doping in cuprate-titanate heterostructures: Consequences for superconducting field effect

Natalia Pavlenko[1], Ilya Elfimov[2], Thilo Kopp[1], and G.A.Sawatzky[2]

[1] *Center for Electronic Correlations and Magnetism, Universität Augsburg, 86135 Augsburg, Germany*
[2] *Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada V6T1Z1*

Heterostructures consisting of $YBa_2Cu_3O_{7-d}$-films grown on $SrTiO_3$-layers are of essential importance due to their applications in superconducting field effect devices. Here we study electronic states at interfaces between $YBa_2Cu_3O_6$ and $SrTiO_3$ using a local spin density approximation with intra-atomic Coulomb repulsion (LSDA+U). We show that the "polar catastrophe" at the cuprate/titanate interfaces leads to an effective interface pre-doping by holes and to a metallic state in heterostructure consisting of initially insulating layers. In this metallic state, the hole carriers are concentrated predominantly in the CuO_2-layers and in the first interface TiO_2 and SrO planes. An extra (hole) charge carrier results in a highly pre-doped CuO_2-layer which can have significant consequences for the superconducting properties of field-effect devices realized on the basis of cuprate/titanate superlattices. In order to make a step towards perfect interfaces, we discuss the heterostructures of $Sr_2CuO_2Cl_2$ and related superconducting cuprates as alternative candidates to probe the electrostatic field effect.

Superconducting Qubits

Franco Nori, Y. X. Liu, L. F. Wei, J. Q. You.

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This talk overviews our theoretical studies (some done with J.S. Tsai and Y. Nakamura) on superconducting (SC) circuits and quantum information (see, e.g., Phys. Today 58(11), 42 (2005)) including: SC qubits coupled and addressed as trapped ions (cond-mat/0509236); Controllable coupling between flux qubits (PRL 96, 067003 (2006)); Hybridized solid-state qubit in the charge-flux regime (PRB 73, 014510 (2006)); Generation of entangled states (PRL 97, in press (2006)); Testing Bell's inequality in SC qubits (PRB 72, 104516 (2005)); Quantum computation with SC qubits by using a current-biased information, PRB 71, 134506 (2005); Tomographic measurements on SC qubit states, PRB 72, 014547 (2005); Preparation of macroscopic quantum superposition states of a cavity field via coupling to a SC charge qubit, PRA 71, 063820 (2005); Coupling Josephson qubits via a current-biased information bus (EPL 67, 1004 (2004)); Generation of nonclassical photon states using a SC qubit in a microcavity (EPL 67, 941-947 (2004)); Fast two-bit operations in inductively coupled flux qubits, (PRB 71, 024532 (2005)); Controllable manipulation and entanglement of macroscopic quantum states in coupled charge qubits, (PRB 68, 024510 (2003)); Scalable quantum computing with SC charge qubits; PRL 89, 197902 (2002); and quantum information processing with SC qubits in a microwave field (PRB 68, 064509 (2003)).

Dynamics of a Strongly Driven Superconducting Qubit

Sergio O. Valenzuela

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The persistent-current (PC) qubit is an artificial atom, which exhibits avoided crossings between consecutive energy levels. Driving the qubit with a large-amplitude excitation sweeps it through one or more avoided crossings two times per period. Here we present our recent demonstration of Mach-Zehnder (MZ)-type interferometry with a niobium PC qubit, where induced Landau-Zener (LZ) transitions, at the avoided crossing between the ground and first-excited states, act as coherent beamsplitters, and the accumulated phase varies with the time between LZ transitions. The resulting quantum interference gives rise to an oscillatory dependence of the qubit level populations on flux detuning and the driving field amplitude. Interestingly, these interference fringes, which at high frequencies consist of individual multiphoton resonances, persist even for driving frequencies smaller than the decoherence rate, where individual resonances are no longer distinguishable. Finally, we show that a series of interferometers can be created at large enough driving field amplitudes by incorporating the avoided crossings at higher energies.

This research was done in collaboration with D.M. Berns, A.V. Shytov, L.S. Levitov, and T.P. Orlando, (MIT); and W.D. Oliver, (MIT Lincoln Laboratory) and was supported by the AFOSR (F49620-01-1-0457) under the DURINT program and the DoD under Air Force contract FA8721-05-C-0002.

Crossed Andreev Reflection, Elastic Cotunneling and Charge Imbalance: Non-Local Effects in Normal-Superconducting Systems

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Nonlocal, coherent effects are hallmarks of quantum mechanics. Recently, interest has grown in nonlocal processes that coherently couple electrons in spatially separated normal metals (N) linked by a superconductor (S).[1–3] The correlations induced between the spatially separated electrons are predicted to give rise to non-local voltages in response to a drive current below the superconducting transition. Here we present experimental evidence for such non-local voltages in normal-superconducting systems with highly transparent interfaces, and demonstrate that they exhibit the predicted spatial evolution. Our results have implications for the entanglement of electrons in normal-metal/superconducting systems.

Current-Phase Relations and Spontaneous Currents in Superconductor-Ferromagnet-Superconductor p**-Josephson junctions and arrays**

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The existence of π-Josephson junctions, characterized by a negative critical current and a minimum energy at a phase difference of π, was proposed over 25 years ago but only recently demonstrated. In this talk, I will describe experiments on Superconductor-Ferromagnet-Superconductor (SFS) Josephson junctions that exhibit a transition from conventional 0-junction to π-junction behavior as a function of temperature or barrier thickness. We have used a phase-sensitive SQUID technique to measure directly the current-phase relation, allowing us to verify the π-junction behavior and to determine if any $\sin(2\phi)$ component is present in the crossover region as predicted by some models. We have compared these results with measurements of subharmonic microwave-induced Shapiro steps and anomalous critical current diffraction patterns that have been cited as evidence for higher-order Josephson tunneling components. I will also present magnetic field images of 2-D arrays of SFS junctions obtained by Scanning SQUID Microscopy. We observe spontaneously-generated circulating currents in zero applied magnetic field in fully-frustrated arrays with an odd number of π-junctions in each cell and in non-uniformly frustrated arrays with different numbers of π-junctions per cell. Such π-Josephson junction circuits have potential applications in digital and quantum computing.

In collaboration with Sergey Frolov, Micah Stoutimore, and Martin Stehno (*UIUC*) and Valery Ryazanov, Vladimir Oboznov, Vitaly Bolginov, and Olexey Feofanov (*Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Russia).*

Andreev Reflection Spectroscopy of the Pure and Cd-doped Heavy Fermion Superconductor $CeCoIn_5$: Detecting Order Parameter Symmetry and Competing Phases

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Andreev reflection spectroscopy has been performed on the heavy-fermion superconductor (HFS) $CeCoIn_5$ single crystals along three different crystallographic orientations, (001), (110), and (100), using Au tips as counter-electrodes [1-4]. Dynamic conductance spectra are reproducible over wide temperature ranges and consistent with each other, ensuring the spectroscopic nature. Features common to all directions are: i) asymmetric behaviors of the background conductance, which we attribute to the emerging coherent heavy-fermion liquid; ii) energy scales (~1 meV) for conductance enhancement due to Andreev reflection; iii) magnitudes of enhanced zero-bias conductance (10 - 13 %). These values are an order of magnitude smaller than the predicted value by the Blonder-Tinkham-Klapwijk (BTK) theory, but comparable to those reported for other HFSs. Using the *d*-wave (extended) BTK model, we obtain an energy gap of ~ 460 ? eV. However, it is found that, considering the mismatch in Fermi surface parameters, extended BTK models do not account for the temperature dependence of our conductance spectra. A qualitative comparison of the conductance spectra with calculated curves shows a consistency with d_{x2-y2}-symmetry, providing the first spectroscopic evidence for the order parameter symmetry and resolving the controversy over the location of the line nodes. Preliminary measurements on Cd-doped $CeCoIn_5$, at the 10% doping level, show characteristics consistent with antiferromagnetic and subsequent superconducting transitions with decreasing temperature. The roles of competing phases in this material will be discussed.

*This work is in collaboration with Wan Kyu Park, J. L. Sarrao, J. N. Thompson, L. Pham, T. Park, S. Maquilon and Z. Fisk,

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REFERENCES:

1. W. K. Park et al, Phys. Rev. B **72**, 052509-1-4 (2005).
2. W. K. Park and L. H. Greene, Rev. Sci. Instrum. **77**, 023905 (2006).
3. W. K. Park et al, Proceedings of SPIE **5932** (SPIE, Bellingham, WA, 2005), 59321Q-1-13.
4. Wan Kyu Park et al, Proc. M2S-HTSC-VIII, July 9-14, 2006, Dresden, cond-mat/0606535.

Josephson current through a strong ferromagnet

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Josephson current through superconductor/ferromagnet/superconductor junctions has attracted great interest in recent years. Since the supercurrent is carried by spin-singlet Cooper pairs in conventional superconductors, the superconducting order parameter of a superconductor decays quickly in a strong ferromagnet like a transition-metal ferromagnet or oxide ferromagnet, so that the existence of singlet pairs is totally prohibited in strong ferromagnets. Recently, the Josephson supercurrent through a half-metallic ferromagnet CrO_2 has been reported [1] and a spin triplet supercurrent through CrO_2 is inferred. It has been predicted that this rapid spatial decay does not occur if spin-triplet superconductivity could be induced in the ferromagnet [2,3]. The underlying physics for occurring spin-triplet superconductivity is a conversion from spin singlet pairs to spin triplets at the interface. However, these theories do not take into account the dynamic aspect of magnetization in the conversion process. In this paper, we theoretically study the Josephson coupling between two singlet superconductors through a half-metallic ferromagnet by taking account of spin-assisted tunneling of electrons between the half-metal and the superconductors, and show that a Josephson coupling appears between the superconductors by inducing triplet correlations in the half-metal. We predict a new type of Josephson effect controlled by magnetization dynamics of a strong ferromagnet between superconductors [4].

[1] R. S. Keizer *et al*., Nature (London) 439, 825 (2006). [2] F. S. Bergeret *et al*., Phys. Rev. Lett. 86, 4096-4099 (2001). [3] M. Eschrig *et al.*, Phys. Rev. Lett. 90, 137003 (2003). [4] S. Takahashi *et al.* (unpublished).

Experiments with fractional flux quanta

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Superconducting ring structures with built-in phase shifts, e.g. originating from the incorporation of pi-Josephson junctions or unconventional (d-wave) superconductors, exhibit a spontaneous magnetization. The magnitude of the magnetic flux increases to a half-integer flux quantum for rings approaching the large inductance limit.

We have employed this half-flux quantum effect in hybrid high-T_c vs. low-T_c Josephson structures for basic studies, e.g. on the order parameter symmetry in the high-T_c cuprates [1], as well as for the development of novel (quantum)-electronic devices [2]. In this presentation I will discuss various experiments in both directions.

[1]: Kirtley et al., Nature Physics 2, 190 (2006)
[2]: Ortlepp et al., Science 312, 1495 (2006)

Unconventional proximity effects in superconductor-ferromagnet hybrids

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Magnetism and superconductivity are competitive types of order in correlated electron systems. However, when a magnetic material is brought in contact with a superconducting material to build a junction, a coexistence region exists near the boundary that can modify the properties of the heterostructure in a qualitative way. In the case of a ferromagnet in contact with a singlet superconductor, the importance of triplet pairing correlations in the interface region recently became the focus of research. Such triplet correlations have unusual properties. They are typically odd in frequency for the case of a diffusive material. For clean materials in addition a triplet component even in frequency but odd in momentum is present. We have predicted that such triplet correlations can lead to an unusual indirect Josephson effect in a superconductor/half-metal/superconductor structure [M. Eschrig et al, Phys. Rev. Lett. 90, 137003 (2003)].
In the case of a long half-metal such a Josephson effect is solely due to equal-pair triplet superconducting correlations. The triplet supercurrent is converted into a singlet current in the interface regions of the structure. Such an effect has been experimentally observed very recently [R. S. Keizer et al, Nature 439, 825, (2006)].

Transport Properties of Ferromagnetic Semiconductors with Superconducting Electrodes

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Superconductor/ferromagnet (S/F) junctions have attracted considerable interest both theoretically and experimentally [1]. This is because new quantum phenomena can be expected from the interplay between the superconductivity and the spin polarization of the ferromagnet. Ferromagnetic metals such as Ni-Fe and Co have already been used as ferromagnetic materials. However, such ferromagnetic metals have a large number of carriers contributing to the transport and it is difficult to control this number with the electric field effect. In contrast, since p-$In_{0.96}Mn_{0.04}As$ is a kind of ferromagnetic semiconductor [2], it is reasonable to suppose that the number of carriers in p-$In_{0.96}Mn_{0.04}As$ can be changed by using the electric field effect. In this paper, we report on the transport properties of ferromagnetic p-$In_{0.96}Mn_{0.04}As$ with Nb superconducting electrodes.

[1] For example, *Towards the Controllable Quantum States*, edited by H. Takayanagi et al, Singapore: World Scientific, 2003.

[2]H. Munekata, *Mater. Sci. Eng.* **B31**, 151-156 (1995).

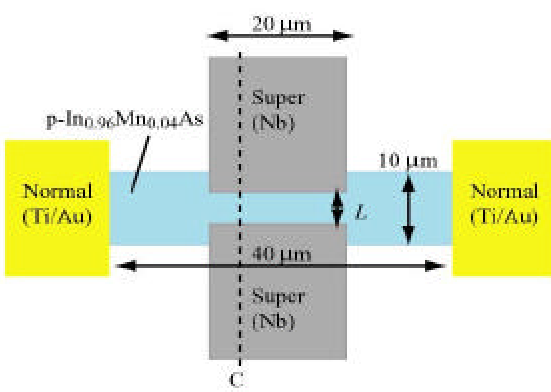

FIGURE 1. Schematic diagram of a superconductor-ferromagnet junction: top view.

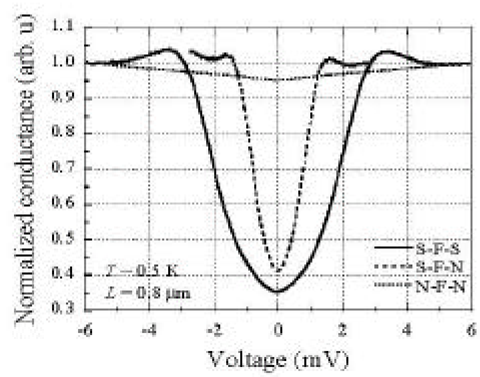

FIGURE 2. Normalized differential conductance as a function of bias voltage for three different measurement setups at 0.5 K.

Vortex configurations in mesoscopic superconductors: direct observation using Bitter decoration

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The properties of a type-II superconductor change dramatically as it becomes mesoscopic, i.e., can accommodate only a small number of vortices. In magnetic field H, such a superconductor resides in one of a series of discrete states characterized by vorticity L. We have studied vortex configurations in mesoscopic superconducting disks directly, by using the Bitter decoration technique. Two types of mesoscopic samples have been investigated: individual circular disks made from a 150 nm thick Nb film and 0.5 to 1.5 µm tall circular 'pillars' etched at the top of Nb single crystals. Strong diamagnetic response have been observed both for thin-film disks and the 'pillars' on single crystals, even though in the latter case only a tiny fraction of the total length of the vortices was subject to additional interaction with the disk edge.

For a broad range of vorticities L the circular geometry of the disks was found to lead to the formation of concentric shells of vortices. Using statistical analysis of the images obtained on hundreds of disks of different sizes in a range of magnetic fields we were able to trace the evolution of vortex states with increasing L and to distinguish between stable and metastable configurations of interacting vortices. Only one vortex configuration was found for each L at small vorticities ($L \leq 4$) but up to four different states with the same L were observed for larger L. Analysis of shell filling with increasing vorticity allowed us to identify 'magic' numbers corresponding to the appearance of consecutive new shells.
Furthermore, we investigated the effect of pinning on vortex configurations in confined geometry: While weak pinning only leads to vortex displacements from their ideal positions in vortex shells, strong pinning leads to the formation of vortex clusters and, under certain conditions, giant vortices. The experimental results are in good agreement with the results of numerical simulations.

Indications of a Field Dependence Vortex Core Size in $CeCoIn_5$

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Since the discovery of the heavy-fermion superconductor $CeCoIn_5$, a plethora of fascinating phenomena have been observed in this material. Among these one finds the highest critical temperature (T_c = 2.3 K) in any heavy-fermion superconductor, d-wave pairing symmetry, non-Fermi liquid behaviour, field- and pressure induced quantum critical points, and strong indications for the first realization of the socalled Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) non-uniform superconducting state. In addition CeCoIn5 is found to be an extreme case of a clean, high-k (k 25 – 50) superconductor, with a mean free path of the order 10 to 1000 times the coherence length.

Using small-angle neutron scattering (SANS) we have imaged the flux-line lattice (FLL) in $CeCoIn_5$. At low fields a hexagonal FLL is observed, which reorients and undergoes a first order transition to a rhombic (distorted square) symmetry as the field is increased above 0.55 T. As the field is increased further, the FLL approaches a square symmetry.

Measurements of the FLL reflectivity yields a field-independent form factor, in striking contrast to the exponential decrease usually observed. Applying a traditional analysis where the field dependence of the form factor is used to estimate the superconducting coherence length, would correspond to the unphysical situation of a diverging field at the center of the vortex core. In stead we believe that the the field-independent form factor is due to a field-induced change in the fundamental superconducting lengthscales (penetration depth and coherence length). The most likely scenario is a field depencent vortex core size, ? $H^{-1/2}$, in qualitative agreement with recent theoretical predictions for ultra-clean, high-k superconductors [V. G. Kogan and N. V. Zhelezina, Phys. Rev. B 71, 134505 (2005).

Electronic “checkerboard” and superconductivity in $Ca_{2-x}Na_xCuO_2Cl_2$

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Coexistence or competition of various electronic phases has been one of the most important issues in the physics of strongly correlated electron systems. Especially, possible electronic orders in high-T_c cuprates have attracted much attention. Recent scanning tunneling microscopy/spectroscopy (STM/STS) measurements on high-T_c cuprates have revealed the “checkerboard” local density-of-state modulations in the vortex core [1], above T_c [2], and in heavily underdoped regime [3]. In order to make clear the relationship between the checkerboard states and superconductivity, we have performed high-resolution STM/STS on optimally-doped $Ca_{2-x}Na_xCuO_2Cl_2$ crystals with T_c = 25 ~ 28 K. Even in these optimally-doped crystals, the checkerboard modulation, which is characterized by the spatially varying V-shaped pseudo-gap (PG) below energy $|E|$ ~ 100 meV, is clearly observed. In addition to the PG, we have found another small gap below $|E|$ ~ 10 mV with coherence-peak-like structures at the gap edges. The gap-edge peak is spatially inhomogeneous, correlates with the checkerboard modulation, and tends to disappear at elevated temperatures or under high magnetic field. In addition, we found a quasi-particle interference pattern which is consistent with the energy dispersion around the gap nodes. These results suggest that the small gap is related to superconductivity and the checkerboard modulation coexists with superconductivity.

This work has been done in collaboration with Y. Kohsaka, J. C. Davis, C. Lupien I. Yamada, M. Azuma, M. Takano, K. Ohishi, and H. Takagi

[1] J. E. Hoffman *et al.*, Science 195 (2002) 466.
[2] M. Vershinin *et al.*, Science 303 (2004) 1995.
[3] T. Hanaguri *et al.*, Nature 430 (2004) 1001.

Magneto-optical Imaging and Colossal Magnetoresistance in Manganites

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Magneto-optical imaging is applied to several manganite systems. We have found that the shape of magnetic domains strongly depends on the field history. In a certain class of manganites, the arrangement of magnetic domains reflects the residual defects during the crystal growth [1]. In $(La,Pr)_{1-x}Sr_xMnO_3$, where microscopic phase separation is reported by STM observations, our magneto-optical imaging unveiled the presence of macroscopic inhomogeneity related to the phase separation into ferromagnetic metals and charge-ordered insulators [2]. Utilizing the very sharp resistivity change at the insulator-metal transition, we have demonstrated the possibility of low-field colossal magnetoresistance at low temperatures [3]. This phenomenon is not limited to low temperatures. We have successfully realized a similar colossal magnetoresistance effect in $La_{1-x}Sr_xMnO_3$ above room temperature [4].

[1] Y. Tokunaga, M. Tokunaga, and T. Tamegai, Phys. Rev. B **71**, 012408 (2005).
[2] M. Tokunaga, Y. Tokunaga, and T. Tamegai, Phys. Rev. Lett. **93**, 037203 (2004).
[3] M. Tokunaga, H. Song, Y. Tokunaga, T. Tamegai, Phys. Rev. Lett. **94**, 157203 (2005).
[4] S. Imamori, M. Tokunaga, S. Hakuta, and T. Tamegai, submitted to Appl. Phys. Lett.

Imaging Transport Currents and I-V curves in Second Generation Coated Conductors

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We studied second generation (2G) MOD/RABiTS YBCO superconducting tapes on flexible magnetic substrates. Direct magneto-optical observations show that the magnetic flux penetration and the transport current flow are dominated by the network of weak links in the YBCO film defined by the granular structure of the substrate. The vortex penetration patterns in external magnetic fields show remarkable positive (parallel to the field) and negative (antiparallel to the field) flux islands at the fractal flux penetration front. They are associated with the weak links and the interaction of vortices with the underlying ferromagnet. The flux patterns due to an applied field or due to applied current pulses are compared with the network of grain boundaries in the magnetic substrate. These can be clearly observed at $T>T_C$ due to magnetic contrast arising from the misalignment of the easy magnetization axes of the grains. A direct mapping allows to pinpoint critical spots reducing the superconducting performance of the tapes. These key spots, precisely defined spatially, are then structurally analyzed to establish pathways for enhancing critical currents.

Simultaneous measurements of I-V curves and imaging of the current flow in micro-bridges manufactured in chosen spots of 2G YBCO tapes give a straight insight to the current limiting mechanism and reveals the development of the thermal runaway effect at increasing currents.

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STM in Mesoscopic Single Crystal Superconductors

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We present scanning tunnelling microscopy study of the vortex lattice configurations in a mesoscopic single crystal superconductor – normal metal heterostructure. First, we used a novel fabrication method that leads to well-controlled engineered superconducting surfaces containing periodic array of normal metal pinning centers inside a single crystal superconductor. STM vortex imaging in these structures shows co-existence of a strongly interacting multiquanta vortex lattice and interstitial Abrikosov vortices. As a result we obtain a composite magnetic flux distribution which undergoes a series of transitions between different topological configuration states. The vortex configuration states are strongly dependent on the nanoscale architecture of the superconductor and applied magnetic field. Scanning tunnelling spectroscopy images show the evolution and transitions of vortex topological states when the number of flux quanta in the system changes.

Vortex Manipulation and Ratchets in Nanostructured Superconductors and Superconductor/Ferromagnet Hybrids (*)

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We have studied the vortex dc transport induced by an ac current in an Al film with a nanoengineered array of two different size antidots placed close to each other. The vortex response to the ac current is investigated by detailed measurements of the voltage output as a function of the ac current amplitude, magnetic field and temperature. These measurements revealed pronounced voltage rectification effects which are characterized by the two critical depinning forces of the asymmetric potential. The shape of the net dc voltage as a function of the excitation amplitude indicates that our vortex ratchet behaves in a way very different from standard overdamped models. Rather, as demonstrated by the observed output signal, the repinning force, necessary to stop vortex motion, is considerably smaller than the depinning force, resembling the behavior of the so-called inertia ratchets. Calculations based on an underdamped ratchet model provide a very good fit to the experimental data (*Phys. Rev. Lett.* **94**, 057003 (2005)). Multiple sign reversals of the ratchet effect have been found as the vortex density is increased (*Nature*, **440**, 651 (2006)).

Artificial hybrid superconductor-ferromagnet (S/F) systems have been used as model systems to reveal the interplay between competing superconducting and magnetic order parameters, and to verify the existence of new physical phenomena, including the recently predicted domain-wall superconductivity (DWS). The first experimental observation of the DWS in superconductor-ferromagnet Nb/$BaFe_{12}O_{19}$ hybrids is discussed here. We found that the critical temperature T_c of the superconductivity nucleation increases with increasing field until it reaches the saturation field of $BaFe_{12}O_{19}$. Pronounced hysteresis effects have been found in resistive transitions. We argue that the compensation of the applied field by the stray fields of the magnetic domains as well as the change in the domain structure induced by the superconducting Nb layer are responsible for the appearance of the DWS and the coexistence of superconductivity and magnetism in the S/F hybrids (*Nature Materials* **3**, 793 (2004)). Nucleation of superconductivity in the F/S/F trilayers (*Phys. Rev. Lett.* **95**, 227003 (2005)) and superconducting square with magnetic dot (*Phys. Rev. Lett.* **95**, 237003 (2005)) will be also discussed.

(*) In collaboration with J. Van de Vondel, W. Gillijns, N. Schildermans, K. Vervaeke, J. Fritzsche, C.C. de Souza Silva, A. Aladyshkin, C. Carballeira, Z.R. Yang, A. Silhanek

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Superconducting and Magnetic Vortices in Periodical Arrays with Spheroidal Shape of Nano-Elements

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Previous research of vortex matter in nano-arrays dealt almost exclusively with 2D arrays prepared by standard lithography. The geometries in such arrays are normally cylinders or rectangular prisms. In contrast we present results for samples from template self-assembly fabrication methods with spheroidal shape of nano-elements resulting in a pronounced 3D architecture. Methods based on templates formed by the self-assembly of colloidal particles have demonstrated promise for a number of applications such as photonic materials, microchip reactors and biosensors. We use ordered templates for the electro-deposition of different magnetic and superconducting materials. Further developments of this template preparation method allow us to obtain dot arrays and even more complicated structures. This technique offers new opportunities, which can not be realized by standard lithographic methods.

Pb anti-dot arrays, prepared using latex sphere template, show pronounced Little-Parks oscillations in T_c and matching effects in magnetization and magnetic susceptibility. In contrast to conventional lithographic arrays the samples with spherical cavities demonstrate significantly reduced pinning strength favoring the formation of commensurate states. The ac-flux penetration acquires a hybrid intra- and inter-valley regime. For high ac-drives an unusual inversion to paramagnetic ac-shielding is found at commensurate states.

In magnetic anti-dot arrays we observe large increase in coercive field produced by nanoscale (8-1000nm) holes. We also find that the patterning transverse to the plane of the 3D nanostructured films governs the magnetic behaviour. In particular, the coercive field was found to demonstrate an oscillatory dependence on film thickness. Computational micromagnetic modelling is presented which supports the interpretation of this phenomenon in terms of the periodical arrangements of holes in the direction perpendicular to the film plane. The observed coercivity data demonstrates that 3D patterned magnetic materials are prototypes of a new class of geometrical multilayer structures in which the layering is due to local shape effects rather then compositional differences. In magnetic dot arrays we have explored the genesis of a 3D magnetic vortex and determined the critical dot size. In this case, in difference from standard disc-shaped dots, the direction of the magnetic vortex is not locked to the normal of the dot. Suppression of the shape induced magnetic anisotropy in our quasi-spherical dots is an important factor for the new behaviour of magnetic vortices.

Our results demonstrate that self-assembly template methods are emerging as a viable, low cost route to prepare sub-micron structures. The 3D architecture of these structures with spheroidal shape of nano-elements produces many unique properties absent in nanostructures prepared by conventional lithographical techniques.

Magnetic Nanowires/Superconductor Systems

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We discuss properties of hybrid systems which consist of an array of magnetic nanowires (nanorods) embedded in/or covered by a superconductor film. The interaction is provided by the magnetic field generated by magnetic nanowires and supercurrents. The magnetic flux from magnetic nanowires can pin vortices or create them, changing the transport properties and transition temperature of the superconductor. On the other hand, the magnetic field from supercurrents (vortices) strongly interacts with the magnetic subsystem leading to formation of coupled magnetic-superconducting topological defects. We discuss theoretical predictions and experimental results.

Interplay between ferromagnetism and superconductivity in cuprate / manganite structures

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Artificial ferromagnetic/superconducting (F/S) hybrids are very amenable to study coexistence and competition between these long range phenomena. In ferromagnet/superconductor/ferromagnet (F/S/F) structures with thin superconductors the critical temperature is modulated by the relative orientation of the magnetization in the F layers. In proximity coupled trilayers, a larger T_c in the antiparallel (AP) configuration results from the averaging (compensation) of the exchange field over the coherent volume. These concepts have been experimentally realized in structures combining low-T_c superconductors and transition metal ferromagnets. In this talk I will focus in F/S/F structures made of $YBa_2Cu_3O_7$ (YBCO) and $La_{0.7}Ca_{0.3}MnO_3$ (LCMO). The high degree of spin polarization of the LCMO conduction band, together with the d-wave superconductivity of the YBCO make this F/S system an adequate candidate for the search of novel spin dependent effects. Moreover, since in these manganite / cuprate junctions F/S proximity effect should be absent the F/S interplay may occur differently and interesting novel effects may show up. Specifically, I will show that in LCMO/YBCO/LCMO trilayers the T_c modulation effect with magnetic alignment, in contrast to the conventional F/S/F superconducting spin switch, leads to a smaller T_c in the antiparallel (AP) than in the parallel (P) configuration of the magnetizations of the LCMO layers. If a temperature is set in between both temperatures ($T_c^P<T<T_c^{AP}$), a magnetic field can be used to valve between both configurations yielding large magnetoresistance (MR) values. This effect will be discussed in terms enhanced scattering in the AF configuration of thermally diffused spin polarized quasiparticles.

Work done in collaboration with V. Peña[1], C. Visani[1], J. Garcia Barriocanal[1], Z. Sefrioui[1], D. Arias[1], C. Leon[1] , N. Nemes[2], M. Garcia Hernandez[2], S. G. E. te Velthuis[3], A. Hoffmann[3], M. Varela[4], S. J. Pennycook[4]

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Vortex Chirality

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Recent studies on Co, Ni and permalloy rings have shown that a totally flux-closed magnetic vortex is stable at remanence. The two chiralities of the vortex, clock-wise and anti-clock-wise, have been proposed as the carriers for the stored information that could be read in a magneto-resistance-based device. To visualize the magnetization reversal process in individual rings we employed several different imaging techniques: magnetic force icroscopy (MFM), scanning Hall microscopy, magneto-optical (MO) imaging, Lorentz STEM (LSTEM) and scanning electron microscopy with polarization analysis (SEMPA). We found that MO, LSTEM and SEMPA allow a direct determination of magnetic vortex chiralities and that by controlling the shape of the nanoscale magnetic ring and the direction of applied magnetic field we can precisely tune the switching mechanism and reliably predict the chirality of the vortex states. The experimental results were compared with detailed micromagnetic simulations.

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Manipulation of Spin and Charge in Magnetic Semiconductor Hybrids

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Magnetic semiconductors are known to exhibit giant Zeeman response with effective gyromagnetic ratios of order 100-1000. This property can be used to create spin-polarized charge textures with a highly inhomogeneous external magnetic field. I will discuss several hybrid systems in which the external magnetic field is supplied by either nanomagnets or superconducting vortices. In particular, I will show how recent progress in superconducting vortex manipulation can be used to manipulate spin and charge textures in magnetic semiconductors.

Ground states of Josephson vortex lattice in layered superconductors at different magnetic fields and temperatures

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We considered the ground-state configurations of the Josephson vortex lattice in layered superconductors. Due to commensurability effects with the layered structure and rotational degeneracy of the lattice energy in the London approximation, the lattice has multiple ground-state configurations, both aligned with the layers and rotated at finite angle. With increasing magnetic field the lattice switches between these configurations via sequence of first-order phase transitions until it transforms into dense lattice via intermediate sheared dense-lattice state. As the Josephson vortices preferably fluctuate along the layers, thermal fluctuations eliminate the rotational degeneracy and therefore have a significant influence on ground-state selection favoring the simplest aligned configurations.

Dynamics of Josephson vortex lattice in Bi-2212 stacked structures: melting, interaction with pancake vortex lines and columnar defects

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We studied several factors affecting Josephson flux-flow (JFF) in Bi-2212 stacked junctions: (1) effect of Josephson vortex lattice (JVL) melting, (2) influence of pancake vortex lines (PVLs), (3) influence of columnar defects (CDs) including the case when CDs are filled by PVLs. The JVL melting has been probed by a disappearance of the oscillations of the flux-flow resistance on the parallel magnetic field [1]. In this way we identified the B-T phase diagram of solid vortex state (triangular JVL). This region as shown is restricted by the upper boundary with Berezinskii-Kosterlitz-Thouless phase and the lower boundary, both boundaries meet at B=0.6 T and at temperature lying 3.5 K below the superconducting transition temperature. The upper boundary of the diagram is consistent in general with theoretical predictions. We found that PVLs introduce excess damping for the moving JVL that leads to excess current on the I-V characteristics in the JFF regime. The excess current has a maximum as a function of the bias voltage. Theoretically, the excess damping is attributed to vibrations of PVL induced by the triangular JVL passing through it. The maximum damping in this model occurs when the Josephson oscillation frequency becomes equal to the relaxation frequency of PVL vibrations. We found that irradiation with heavy ions significantly reduces the pancake-vortex damping of JVL motion. This reduction is consistent with the theoretical model. The PVLs trapped by CDs are practically not displaced by JVs and do not contribute to the JVL dissipations.

1. Yu. I. Latyshev, V.N. Pavlenko, A.P. Orlov, and X. Hu, JETP Lett., 82 (2005) 232.

Lock-in **phenomena of Josephson vortices in intrinsic Josephson junctions**

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Lock-in phenomena of Josephson vortices in intrinsic Josephson junctions of high-T_c superconductors have been studied. In highly anisotropic (γ~300) Bi-2212, the pancake vortices behave as if they are independent of the Josephson vortices. We found that the *lock-in* phenomena are the results of the motion of the pancake vortices inside and edge of the junctions. As the result, the *lock-in* strongly depends on the sequence of 1) angle adjustment, 2) temperature schedule and 3) magnetic field schedule. At low temperature, such as below 5 K, the *lock-in* angle exceeds plus/minus 1.0 deg. by the zero field cooling from the temperature above T_c and subsequent applying of magnetic field up to several tesla [1]. The origin of the phenomena will be discussed by the shape of the edge potential for entry and escape for the pancake vortex and the irreversibility temperature. The difference of *lock-in* in less-anisotropic Y-123 IJJs will be discussed.

[1] T. Hatano, *et al*., "*Lock-in* Phenomena of Josephson Vortices under Vicinal Layer Parallel Magnetic Field", Jpn. J. Appl. Phys, **44**, L27-L30 (2004)

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Various vortex states in the vicinity of the *ab*-plane of $Bi_2Sr_2CaCu_2O_{8+?}$ probed by the *c*-axis resistivity of mesoscopic crystals

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It has been discussed whether triangular or square vortex lattice is more stable since the prediction of the vortex lattice by Abrikosov. For Josephson vortex (JV) system, this is an important issue for coherent emission of electromagnetic wave which has been intensively investigated in these years. The authors found oscillation in the JV flow resistance r_{JV} with the period of a single flux quantum Φ_0 in samples with widths less than 5 μm after the finding of r_{JV} oscillation with the period of $\Phi_0/2$ by Ooi *et al*. Although this may be interpreted that a rectangular JV lattice forms because the boundary effect, *i.e.*, surface barrier, overcomes the bulk electromagnetic coupling between layers which prefers triangular JV lattice, some ambiguities between them cannot be removed. It is a purpose of this paper to distinguish triangular and rectangular JV lattices by considering the lock-in transition in addition to the r_{JV} oscillation. In the beginning, we show that the lock-in transition at low fields where the $\Phi_0/2$ oscillation is observed is the transition from pure JV (without pancake) to the crossing lattice (CL). The transition at high magnetic fields where the Φ_0 oscillation is observed includes an oscillatory anomaly which implies the existence of intermediate vortex states between the JV state and CL state. We also observed a broadening of the lock-in transition in high field region. This is another issue to be discussed with the relation to the tilted lattice suggested theoretically by Savele'v *et al*.

Confinement Effects of Josephson Vortices in Layered Cuprate High-Tc Superconductors

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In order to systematically explain the in-plane size effects for the periodical oscillation[1-3] of the Josephson-vortex flow resistance on the magnetic field, we numerically explore static lattice structures[4] of Josephson vortices in layered High-T_c superconductors with finite in-plane sizes from sub-μm to more than 10 μm. By simulating slow quenching processes from high temperature in the use of an over damped version of the coupled sine-Gordon equation including the thermal noise, we obtain an in-plane size dependent H-T diagram of lattice structures of Josephson vortices. The numerical results reveal that in sub-μm size the rectangular lattice is a widely-spread major structure in H-T diagram and the triangular lattice becomes a minor one which emerges only around the specific magnetic field supplying $n\phi_?$ per one junction area. With increasing the in-plane size, the triangular-lattice phase region gradually expands, and the rectangular one disappears more than 10μm. We simply explain these results by considering a relation between the in-plane variation of the phase difference and Lawrence-Doniach free energy[4]. These results suggest that sub-μ m size layered High-T_c superconductors are promising for future device applications.

References:

[1] S.Ooi, T.Mochiku, and K.Hirata, *Phys.Rev.Lett.*, **89,** 247002(2002).
[2] M.Machida, *Phys.Rev.Lett*., **90**,037001(2003).
[3] A. E. Koshelev, *Phys.Rev.B**66***, 224514 (2002).
[4] M.Machida, *Phys. Rev. Lett*., **96**, 097002(2006).

Magnetic Field Dependence of the Lock-in Transition in $Bi_2Sr_2CaCu_2O_{8+d}$ Mesoscopic Single Crystals

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We have investigated lock-in transition phenomena from crossing lattice state to Josephson vortex state, which occurs very sharply like the first order transition in the mesoscopic intrinsic Josephson junctions of $Bi_2Sr_2CaCu_2O_{8+\delta}$?(Bi2212) single crystals. We have measured angular dependence of the *c*-axis resistivity as functions of magnetic fields, *c*-axis currents, and temperatures. In the lock-in state, JV's easily flow along the *ab*-plane due to Lorentz force exerted by the *c*-axis current, resulting in appearance of the JV flow resistance along the *c*-axis. By tilting magnetic field from the *ab*-plane, a sudden drop of the *c*-axis resistance is observed at q?$_{\mathrm{LI}}$ measured from the *ab*-plane, which strongly depends on temperature, applied magnetic field, and the junction size. This sudden drop of the resistivity is a signature to the transition to the crossing lattice state, where JV flow is considered to be highly impeded by the attractive interaction with pancake vortices. The *c*-axis component of the applied magnetic field at the transition angle is regarded as the first penetration field of pancake vortices, namely $H_{\mathrm{pn}} = H\sin q$?$_{\mathrm{LI}}$. It was found that H_{pn} decreased with increasing magnetic field parallel to the *ab*-plane H_{ab} up to about 2 T. Furthermore, in $H_{ab} > 2$ T, the lock-in transition is considerably broadened and H_{pn} begins to depend on the bias currents. These results can at least be explained qualitatively by considering the screening current induced by the Josephson vortices.

Emission of terahertz waves through resonance excitation of Josephson plasma by moving Josephson vortices

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Continuous terahertz electromagnetic waves have various applications such as materials inspection, medical diagnoses, and broadband communications. We consider a mechanism of the emission of the terahertz waves. In high T_c cuprate superconductors, the strongly superconductive CuO_2 layers and almost insulating layers are alternately stacked along the c axis of the crystal and form a naturally multi-connected Josephson junction called the intrinsic Josephson junction (IJJ). In the IJJ there appears an excitation called Josephson plasma in the terahertz frequency rang. Since its frequencies are usually in the inside of the superconducting energy gap, the damping of the excited plasma is very weak. Therefore, the excited plasma will decay by emitting a terahertz electromagnetic wave. When an external magnetic filed and an electric current are respectively applied parallel to the a and c axes of the crystal, the magnetic field induces the Josephson vortices along the a axis and the current drives the vortex flow along the b axis. The vortex flow induces a voltage between the CuO_2 layers. The voltage creates an oscillating current along the c axis due to the ac-Josephson effect. When the frequency of the current is equal to the frequency of the transverse plasma wave propagating along the b axis, the plasma wave is resonantly excited. The excited plasma wave is reflected at both the end surfaces and form a standing wave in the crystal. Thus, the high T_c superconducting sample itself works as a cavity and a part of the input energy is stored in the form of standing wave. Like lasers the part of the stored energy is emitted as terahertz electromagnetic waves from the b-c surfaces in space. The emitted electromagnetic waves are continuous coherent waves with the estimated power being an order of $1000 W/cm^2$. This power is much stronger than those obtained by other methods. The frequency is tunable by changing the applied current. When we use a grating electrode on the ab plane surface, we obtain a powerful emission of terahertz waves from the ab plane surface. The simulation results mentioned above were obtained by using the world leadership supercomputer, the Earth simulator. These experiments are now being done in US and Japan.

Radiation from Josephson oscillations in arti?cial and intrinsic tunneling junction structures

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We derive the radiation power from a single Josephson junction (JJ) and from layered superconductors in the ?ux-?ow regime and in the absence of magnetic ?eld. For JJ case we formulate the boundary conditions for the electric and magnetic ?elds at the edges of the superconducting leads using the Maxwell equations in the dielectric media and ?nd dynamic boundary conditions for the phase difference in JJ which account for the radiation. We derive the fraction of the power fed into JJ transformed into the radiation. In a ?nite-length JJ this fraction is determined by the dissipation inside JJ and it tends to unity as dissipation vanishes independently of mismatch of the junction and dielectric media impedances. We formulate also the dynamic boundary conditions for the phase difference in intrinsic Josephson junctions in highly anisotropic layered superconductors at the boundary with free space. Using these boundary conditions, we solve equations for the phase difference in the linear regime of Josephson oscillations for rectangular and triangular lattices of Josephson vortices. In the case of rectangular lattice for crystals with the thickness along the c-axis much larger than the radiation wavelength we estimate the radiation power per unit length in the direction of magnetic ?eld at the frequency 1 THz as 0.001 N W/cm for Tl-2212 and 0.00004 N W/cm for Bi-2212, N is the number of layers. We get about the same estimate for radiation in the absence of magnetic ?eld. Due to super-radiation regime, up to half of power fed into the crystal may be converted into the radiation. We discuss the radiation contribution to decoherence in qubits made of small-area Josephson junctions in the quantum regime.

Josephson vortex dynamics and THz oscillation in sub-micron intrinsic Josephson junctions

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THz oscillators using intrinsic Josephson junctions (IJJs) have attracted increasing interest because of the high junction density and possible coherent emission. Many experimental investigations and theoretical studies have appeared in the last years however, mainly based on long IJJs. In our case, $Bi_2Sr_2CaCu_2O_{8+\delta}$ IJJs have been fabricated with lateral sizes down to 0.3 μm, the size of a non-linear core of Josephson vortex. A pulse-like dependence of flux flow resistance vs. in-plane magnetic fields implies the vortex dynamics in such narrow junctions would be quite different from that in conventional long IJJs. In addition, evenly-spaced current steps in current-voltage characteristics have been observed, indicating THz oscillation have been excited in sub-micron IJJs.

Also reported will be numerical simulations on vortex dynamics in narrow junctions, and experimental efforts to obtain THz emission from inside of intrinsic Josephson junctions.

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Development of Terahertz Imaging Detector using Superconducting Tunnel Junctions

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We are developing two kinds of terahertz (THz) detector using Nb-based superconducting tunnel junctions (STJs). One of them detects THz waves directly through photon-assisted tunneling process. The detector is sensitive around 0.65 THz with the bandwidth of 10%, and we achieved the noise equivalent power of about 1e-16 W $Hz^{(-1/2)}$. Another one is a broadband detector which can detect THz waves above 0.7 THz. In the detection, the THz photons are absorbed and generated THz phonons in a substrate, which are detected by a STJ fabricated on the substrate.
The details of these detectors will be presented.

Controlling Terahertz Radiation, Critical currents density, and IV Characteristics in Nano-Fabricated Superconductors

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The recent growing interest in terahertz (THz) science and technology is due to its many important applications in physics, astronomy, chemistry, biology, and medicine, including THz imaging, spectroscopy, tomography, medical diagnosis, health monitoring, environmental control, as well as chemical and biological identification. We propose a new class of THz devices, (i) including THz emitters [1] with no impedance mismatch based on JVs moving through in-plane modulated layered superconductors; (ii) THz detectors employing surface Josephson plasma waves [2]; (iii) THz filters based on tunable THz photonic crystals [3], where the band-gap structure is easily controlled by in-plane magnetic field (Josephson vortex density); and THz nonlinear devices [4], including THz strong pulse generators and lenses.

Progress in the fabrication of nanostructures has provided a wide variety of well controlled vortex-confinement topologies, including different regular pinning arrays. We predict [5] analytically and numerically that the Penrose (quasiperiodic) lattice of pinning sites provides an enormous enhancement of critical current density J_c. This large increase in J_c could be useful for applications demanding high J_c's over a wide range of fields.

In analogy to semiconductors, we show that nanostructured superconductor exhibit negative differential resistivity. Moreover, we show [6] that due to heating effect, there exist both N- and S-type in the voltage-current characteristics. This produces self-organized two-dimensional dynamical structures.

[1] S. Savel'ev, V. Yampol’skii, A. Rakhmanov, F. Nori, Phys. Rev. B **72**, 144515 (2005)
[2] S. Savel'ev, V. Yampol’skii, F. Nori, Phys. Rev. Lett. **95**, 187002 (2005)
[3] S. Savel'ev, A. L. Rakhmanov, and F. Nori, Phys. Rev. Lett. **94**, 157004 (2005)
[4] S. Savel'ev, V. Yampol’skii, A. Rakhmanov, F. Nori, Nature Physics, in press (2006)
[5] V. Misko, S. Savel’ev, F. Nori, Phys. Rev. Lett. **95**, 177007 (2005)
[6] V. Misko, S. Savel’ev, F. Nori, Phys. Rev. Lett. **96**, 127004 (2006)

Superconducting Nanowires

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It is important to establish whether there is a limit to how thin a superconducting wire can be, while retaining its superconducting character, and if there is a limit, to determine what sets it. This issue may also be of practical importance in defining the limit to miniaturization of superconducting electronic circuits. At high temperatures, the resistance of linear superconductors is caused by fluctuations called thermally activated phase slips (TAPS). Quantum tunneling of phase slips is another possible source of resistance that is still being debated. I will explain how we use so-called "molecular templates" to fabricate some of the thinnest superconducting wires in order to test these predictions. I will also discuss a number of unexpected results obtained over recent years in such wires with diameters less than 10 nanometers. The list of such effects includes phase slips, Chakravarty-Schmid quantum phase transition, weak Coulomb blockade, and an unusual enhancement of the critical current with the magnetic field.

Suppression of superconductivity in zinc nanowires by bulk superconductors

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Superconductivity in confined system has long been the focus of experimental and theoretical interest. When a superconducting nanowire of a few micrometers in length is connected to two macroscopic normal metal electrodes, a substantial fraction of the nanowire will become resistive due to the proximity effect. When such a wire is sandwiched between two macroscopic superconducting electrodes, the superconductivity of a nanowire is intuitively expected to become more robust through the coupling with its strong superconducting environment. This expectation is not fulfilled in our recent observation in a system consisting of zinc nanowires (ZNWs) between two bulk superconductors (Sn, In and Pb). We found evidence that the superconductivity of the ZNWs of 40 nm in diameter and 2 or 6 um in length is suppressed completely or partially when bulk Sn or In electrodes are superconducting. When bulk Sn or In electrodes are driven into the normal state by applying a magnetic field, the ZNWs switch back to their superconducting state. This anti-proximity effect is significantly weakened when both Sn or In leads were replaced by Pb or one of the two superconducting electrodes is replaced by a normal metal. The phenomenon is not seen in wires with diameters equal to and thicker than 70 nm.

This work is in collaboration with N. Kumar, S. Y. Xu, J. G. Wang, J. Kurtz and M.H.W.Chan and supported by the Center for Nanoscale Science (Penn State MRSEC) funded by NSF under grant DMR-0213623.

Superconductivity and Electrical Transport Properties in Quasi-One Dimensional Conductor Nb_2Se_3

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Single crystals of Nb_2Se_3 have been grown by molten metallic flux technique. Superconducting transition has been observed at T_C=2.0 K by transport, magnetic and thermodynamic measurements. When compared to other Nb-S or Nb-Se quasi-1D superconductors, heat capacity measurements are consistent with the larger electron-phonon coupling constant and more anisotropic gap parameter. Electronic transport and interchain interaction energy in quasi-1D zigzag Nb chains will be discussed and it will be compared among Nb_2Se_3 samples made with different synthesis methods.

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Superconductivity in entirely end-bonded carbon nanotubes

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One-dimensional (1D) systems face some obstructions that prevent the emergence of superconductivity, such as Tomonaga-Luttinger liquid (TLL) states and Peierls transition. Carbon nanotubes (CNs) are one of the best candidates for investigating the possibility of 1D superconductivity and its interplay with such obstructions. Only two groups to our knowledge, however, have experimentally reported superconductivity [1], [2]. In contrast, B-doped diamond and CaC_6 could interestingly exhibit superconductivity with T_c of about 11K [3].

Here, we report that entirely end-bonded multi-walled carbon nanotubes (MWNTs) can exhibit superconductivity with a T_c as high as 12 K [4], which is approximately 30 times greater than T_c reported in [1]. We also find that the emergence of this superconductivity is very sensitive to the junction structures of the Au electrode/MWNTs. This reveals that only MWNTs with optimal numbers of electrically activated shells can allow superconductivity due to intershell effects, resulting in suppression of TLL states. Application of this superconductive MWNT to quantum computation (flux-controlled qu-bit) will be also shown.

[1] M. Kociak, et al., Phys. Rev. Lett. 86, 2416 (2001)
[2] Z. K. Tang, et al., Science 292, 2462 (2001)
[3] E.A.Ekimov et al., Nature (London) 428, 542 (2004); T.E.Weller et al., Nature Physics 1, 39 (2005)
[4] J.Haruyama et al., Phys. Rev. Lett. 96, 057001 (2006)

Superconducting Properties of $NbSe_2$ Nanowires

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Electrical transport measurements were performed on superconducting $NbSe_2$ nanowires with various diameters. It is found that superconducting transition temperature T_c of $NbSe_2$ is lower when the size (diameter) of nanowire becomes smaller. However, the superconducting-state parameters, such as upper critical field H_{c2} and critical current density J_c are considerably enhanced, compared to its bulk counterpart. The implication of our experimental results will be discussed.

Superconductive Nanosolids

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Artificial materials composed of superconductive nanoparticles have emerged as the next frontier of new materials where quantum phenomena can be tailored to generate novel bulk materials behavior. These nanosolids can have programmable electronic properties arising from the fact that the interaction strength and degree of disorder in these materials can be controlled by varying the size and composition of the granules. Each building block of these new materials can be viewed as a tiny cluster of atoms of superconducting elements. I review the progress made in the last several years in understanding the properties of superconductive nanosolids. In particular, I will discuss the following topics:

1) Introduction to physics of superconductive nanosolids
2) Effect of magnetic field on the properties of superconductive nanosolids
3) Future opportunities

Theory for macroscopic quantum tunneling in a stack of capacitively-coupled intrinsic Josephson junctions

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Since the discovery of macroscopic quantum tunneling (MQT) in Bi-2212 intrinsic Josephson junctions (IJJ's) [1] a great interest has been attracted on MQT in the Josephson e? ect from viewpoints of both basic physics and quantum devise applications. In Bi-2212 IJJ's the observed crossover temperature at which MQT appears is about 1K, which is 1-order higher than that in conventional single-Josephson-junction systems. Furthermore, the dissipation e? ect that prevents a quantum tunneling is very weak in spite that the order parameter of high-*T*c cuprates has the d-wave symmetry with nodes. Recently, Jin et al. observed MQT in the switching events to the uniform voltage state in Bi2212 IJJ's where all the junctions are switched into the voltage state and found that the switching rate is greatly enhanced, depending on the number of stacked junctions, N [2]. The observed enhancement in the collective switching is proportional to N^2, which suggests that collective motion of the phase-differences in IJJ's is responsible for the quantum tunneling. In this presentation we propose a theory explaining the N^2-enhancement. We extend the conventional MQT theory for a single particle trapped in a metastable potential minimum to the interacting *N*-particle case. The escape rate proportional to N^2 is derived within the instanton approximation.

References

[1] K. Inomata et al., Phys. Rev. Lett. 95 (2005) 107005.

[2] X. Y. Jin et al., Phys. Rev. Lett. 96 (2006) 177003.

Tuning Unconventional f-Electron Superconductors

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We discuss recent studies of the $CeMIn_5$ and $PuMGa_5$ families of superconductors. Strong evidence exists that these materials are d-wave superconductors. They also display the highest T_c's of known heavy fermion materials. These materials appear to share many properties in common with high-Tc cuprates and with elemental plutonium. Most remarkably, we find that we can tune T_c by two orders of magnitude by varying structural anisotropy and the characteristic spin fluctuation scale. Thus, through a search for new materials in a rather unusual region of the periodic table, we have discovered some apparently general trends for optimizing unconventional superconductors.

Anisotropic Superconducting Phase Diagram and Isotope Effect of C_6Ca

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We present a study of the anisotropic superconducting phase diagram of the new carbon intercalation superconductor C_6Ca employing magnetization, specific heat and magneto-transport measurements. The intercalation of Ca into either flakes of natural graphite or into HOPG was achieved through vapor transport and through immersion into a Li-based flux, respectively. The resulting crystals display an onset of superconductivity near 11.6 K and a transition width of less than 0.5 K as seen in heat capacity and low-field magnetization measurements. A clear step in the heat capacity confirms the bulk nature of the superconducting state. From measurements of the upper critical field, H_{c2}, we determined an in-plane coherence length of $\xi_{ab} \sim 36$ nm. The angular dependence of H_{c2} is well described within the model of effective mass anisotropy yielding a surprisingly low anisotropy parameter of $\Gamma \sim 3.5$ to 4. The isotope effect was determined on a series of samples containing either natural Ca or the ^{44}Ca isotope. T_c is found to be reduced by about 0.5 K in the ^{44}Ca-samples corresponding to an isotope effect coefficient of $\alpha_{Ca} \sim 0.5$. This surprisingly large value of α_{Ca} underscores the importance of Ca-phonons in establishing the superconducting state of C_6Ca.

Superconductivity in graphite intercalation compound C_6Ca

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It is well-known that graphite forms many intercalation compounds with alkali metals, alkali earth metals, halogens, many organic acids, etc. Although many graphite intercalation compounds (GIC's) are known, there are only few compounds known to be superconducting. The typical ones are C_8K with T_c=0.55 K and $C_{4N}C_sBi_x$ with the maximum T_c=4.05 K. Recently, C_6Ca has been reported to be superconducting at T_c=11.6 K, which is three times higher than ever known T_c of GICs. We have synthesized GIC's with Ca in two different methods. One is the direct reaction method and the other is two bulb methods. The final products by both methods showed superconductivity with T_c=11.6 K, although the reaction seems to be much quicker in the former case. We used a piece of commercial high purity HOPG and Ca metal (99.5 % purity) as starting materials. Firstly, Ca is added with Li in 1:3 and heated to 350 ^{o}C in an inert atmosphere to get a liquid Li_3Ca. A piece of HOPG graphite is soaked in the liquid for 10 days, then, cooled quickly down to the room temperature. The product has a metallic shiny silver-golden color and showed a strong tendency of cleavage. The X-ray structural analyses have shown that the observed reflection can be assigned by those of C_6Ca reported before. A piece of product was examined by a SQUID magnetometer and showed strong diamagnetism below 11.6 K. The anisotropy has been measured to be 2.6 with ξ_{ab}=26 nm and ξ_c=9.7 nm.

Understanding and pushing the limits of vortex pinning in $YBa_2Cu_3O_7$-based coated conductors

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The recent progress in the development of $YBa_2Cu_3O_7$ based coated conductors (CC) has been quite impressive. One indication that the technology is approaching maturity is the uniformity and reproducibility of the superconducting transport properties for given processing conditions. This has significantly improved our capability to establish correlations among processing, microstructure and vortex pinning properties. Indeed a reasonably clear picture is now emerging, which allows us to associate the defects in the superconductor with the dependence of the critical current density (J_c) on temperature, magnetic field strength and orientation. As a natural next step, many ways to enhance J_c by nanoscale engineering of pinning defects are now being explored. Perhaps the most remarkable result is that several different approaches have been very successful, even though the pinning mechanisms responsible for the improvement vary from case to case, depending both on the characteristics of the added defects and the growth method of the CC. I will start this talk with an overview of pinning mechanisms in CC, comparing and contrasting the properties of CC made by ex-situ and in-situ methods, which produce laminar and columnar growth, respectively. Then I will discuss some of the successful approaches to increase J_c in both types of films, such as fabrication of multilayers, introduction of nanoparticles, and rare earth substitutions and additions.

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Digital Synthesis of Manganites: An Example of Emergent Phases at Ordered Interfaces

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Digital Synthesis is a technique for atomic layer-by-layer synthesis of complex materials, without introducing the explicit disorder that is nominally associated with chemical doping strategies. Materials with distinct ground states are brought together at fully ordered interfaces in digital superlattices, and the states that emerge as a result of competing interactions, proximity effects, dimensional confinement, charge transfer and broken symmetries at these interfaces are studied. We seek to obtain a microscopic understanding of how spin, charge and structural degrees of freedom organize within digital superlattices, with the ultimate goal of realizing new emergent states at the interfaces of fully ordered correlated materials. In this talk, the basic ideas behind digital synthesis shall be outlined, and a particular example of the La_{1-x} Sr_xMnO_3 system, realized in digital superlattices of $[(LaMnO_3)_{2n}(SrMnO_3)_n]_p$ ($1\leq n \leq 5$) with atomically sharp interfaces, shall be presented. $LaMnO_3$ and $SrMnO_3$ are both antiferromagnetic insulators, but the superlattices are all ferromagnetic below a Curie temperature, accompanied by a transition to a state of lower resistance. Furthermore, a metal-insulator transition is observed as function of increasing superlattice period at low temperatures. For n = 1 and 2, where the nominal Thomas-Fermi screening length is comparable to the superlattice period, a metal is obtained at the lowest temperatures, with high magnetization, consistent with theoretical predictions. In superlattices with $n\geq3$, modulations in hole density cause antiferromagnetic insulating and ferromagnetic conducting phases to coexist. The Curie temperature and magnetization are suppressed, and a re-entrant insulator with variable range hopping is obtained at low temperatures. We propose that intrinsic magnetic disorder arising out of competing phases within the superlattice drives the metal-insulator transition, suppressing the double-exchange mechanism for transport. The distribution of holes within the superlattices above and below the nominal Curie temperature has been studied by scattering and local probes, and these results will be interpreted in light of the transport and magnetization data.

Vortex Line Ordering in the Driven Three-Dimensional Vortex Glass

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University of Rochester

Resistively-shunted-junction dynamics is applied to the three dimensional uniformly frustrated XY model with randomly perturbed couplings, as a model for driven steady states in a type-II superconductor with quenched point pinning. For a disorder strength strong enough to produce a vortex glass in equilibrium, we map the phase diagram as a function of temperature T and uniform driving current I. We find that, within a finite current range $I_{c1}(T)<I<I_{c2}(T)$, the system orders into a set of periodically spaced smectic planes of vortex lines. Smectic planes are short range correlated with neighboring planes; vortex lines within a given plane are periodic along the direction of motion, while disordered along the direction of the applied magnetic field.

*This work has been done in collaboration with Prof. A.K. Ghosh, Jadavpur University, Kolkata, and Prof. P. Olsson, Umea University, Sweden

Creep phenomena of current driven vortices

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Dynamics of vortices under current driving is relevant to many applications of superconducting state. Elegant scaling theory and sophisticated functional renormalization theory have been advanced, and highly nonlinear dynamics is expected at both the zero-temperature depinning critical force and the small force limit with finite temperature. We have performed dynamical simulations for current-driven vortices with point pins. Besides a continuous depinning transition at zero temperature, we also observed creep behaviors at finite temperatures. Especially, the energy barrier defined in the Arrhenius law of creep motion was found to be suppressed to zero linearly when the driving force approaches the zero-temperature critical force from below, and to diverge with a nontrivial, universal exponent as the forces goes to zero. Our simulation results confirm the main theoretical predictions on the creep phenomena.

This talk is based on the work in collaboration with M.-B. Luo.

Vortex glasses with different underlying symmetries; and the dynamics of vortex channel flow

Gergely T. Zimanyi

University of California, Davis

TBA

Local vortex probes: Entanglement, melting, and reordering transitions

Cynthia Reichhardt

Los Alamos National Laboratory

Driving a single particle through a system offers a powerful experimental probe of the nonequilibrium dynamics of a nanoscale medium. Due to recent technical advances, magnetic force microscopy (MFM) can be used to manipulate individual magnetic vortices in a superconductor. We propose an experiment to resolve the controversial issue of whether vortices can entangle like polymers by using an MFM tip to wind one vortex around another and create an artificially entangled vortex state. We also use simulations of local probes to explore other phenomena in vortex lattices, including local melting transitions and nonequilibrium ordering transitions.

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We present a theoretical model for a two-band superconductor in which the character of quasiparticle motion is ballistic in one band and diffusive in the other. This model is based on a novel formulation of coupled quasiclassical Eilenberger and Usadel equations for a multiband superconductor with both a clean and a dirty band [1]. We apply our model to study the intriguing effects of induced superconductivity and impurities on the electronic structure in the vicinity of an isolated vortex. This work was motivated by the observation of vortex states in MgB_2 using scanning tunneling spectroscopy [2]. We assume that superconductivity in the diffusive ('π') band is mostly induced by that in the ballistic ('σ') band, as suggested by experimental evidence for MgB_2. Results are presented for the spatial variation of the order parameter, the current density, and the vortex core spectrum in the two bands. A particularly interesting result emerging from our studies is the possibility of additional bound states near the gap edge in the 'strong' σ band, which arise from coupling to the 'weak' π band. We have also found that the recovery lengths of the order parameters in the two bands are renormalized by Coulomb interactions; and that the current density is dominated in the vortex centre by the σ-band contribution, and outside the vortex core the π band contribution can be substantial, or even dominating.

In our formulation, the strength of the induced superconductivity in the π band is parametrised by the energy gap ratio at zero temperature $T = 0$ (ρ_0) and that near the transition temperature $T = T_c$ (ρ). Other parameters are the ratio of the coherence lengths, ξ_π/ξ_σ, and that of the Fermi-surface density of states, $N_{F\pi}/N_{F\sigma}$. Below the spectra around a vortex are plotted as a function of energy ϵ at various distances r from the vortex centre; for $\rho_0 = \rho = 0.3$ (as in MgB_2 [3]), $\xi_\pi/\xi_\sigma = 5$, $N_{F\pi}/N_{F\sigma} = 1$, and $T/T_c = 0.5$. The π-band spectrum (a) is flat at the vortex centre, in agreement with the experiment on MgB_2 [2]. The σ-band (b) spectrum shows the Caroli-de Gennes-Matricon bound-state bands at low energies, while additional bound states near the gap edge can be seen clearly, which are absent in the single-band case.

[1] K. Tanaka, D. F. Agterberg, J. Kopu, and M. Eschrig, Phys. Rev. B **73**, 220501(R) (2006). [2] M. R. Eskildsen *et al.*, Phys. Rev. Lett. **89**, 187003 (2002); Phys. Rev. B **68**, 100508(R) (2003). [3] M. Iavarone *et al.*, Phys. Rev. Lett. **89**, 187002 (2002).

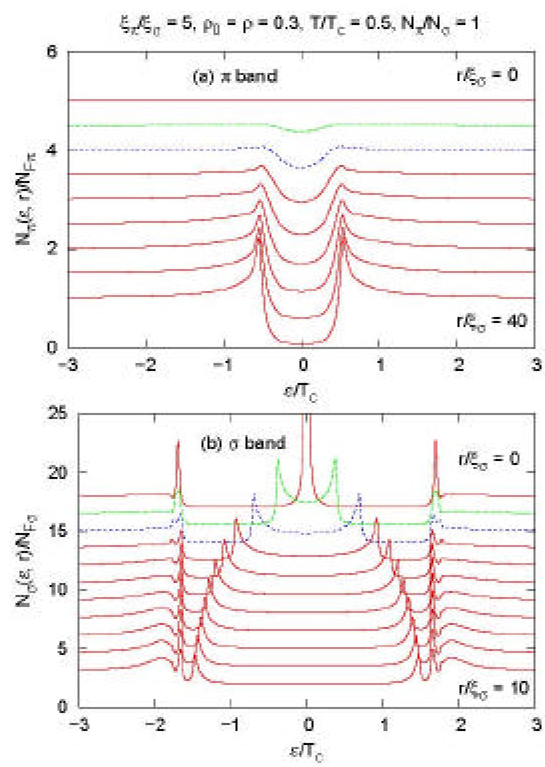

FIG. 1: The local density of states for (a) the dirty 'weak' π band and (b) the clean 'strong' σ band, for $\rho_0 = \rho = 0.3$, $\xi_\pi/\xi_\sigma = 5$, $N_{F\pi}/N_{F\sigma} = 1$, and $T/T_c = 0.5$. The spectra are shifted in a vertical direction for convenience. The existence of bound states near the gap edge in the σ band can be seen clearly.

Novel Vortex Configurations in Elongated Pinning Sites

Charles Reichhardt

Los Alamos National Laboratory

Using numerical simulations for vortices interacting with elongated pinning sites we find a rich variety of vortex configurations and matching effects as a function of vortex density. These configurations agree well with recent experimental results with STM imaging techniques. Our results indicate that the external pinning sites must have a 1D corrugation effect in addition to the 2D periodic pinning potential. We also propose a way to realize a vortex spin ice system with elongated pinning arrays as well as periodic pinning configurations which will generate geometric frustration in the resulting vortex lattice.

Origin of the Matching Effect in a Superconducting Film containing a Hole-array

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Superconducting films containing periodic hole-arrays have been the subject of much interest in recent research. One of the novel phenomena observed in this system is the intriguing matching effect which manifests itself as ‘dips’ in the resistance versus magnetic field curves or ‘peaks’ in the field dependence of the critical current at matching fields where the amount of the magnetic flux through each unit-cell is an integer number of the flux quantum. This effect can be attributed to either flux pinning enhancement at matching fields or the hole-induced suppression of the critical temperature at non-matching fields.

We present an approach to identify the origin of this matching effect observed near the zero-field critical temperature in superconducting Nb films containing triangular hole-arrays. By comparing the magnetic field dependence of the resistance, critical current and critical temperature in perpendicular and parallel field directions, we found that the matching effect in our Nb films containing regular arrays of holes originates from hole-induced suppression of critical temperatures at non-matching fields rather than the widely assumed flux pinning enhancement at matching fields.

Flux-pinning Controlled by Arti?cial Microstructures in Conventional Superconducting Films

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The use of regular arrays of nanoengeneered pinning centers in conventional superconductors is known to enhance the critical temperature $T_c(H)$ and the critical current $J_c(H)$ for all ?elds. In general, the extent to which these centers in?uence the superconducting properties of the system depends on the details of the used structures. In this presentation we will review a hierarchical list of different pinning sites going from the relative weak not fully perforated holes (blind holes), through composite lattices consisting of two interpenetrating antidot arrays and ?nally tunable pinning centers as those generated by arrays of micromagnets. We will show that under particular conditions it becomes possible to manipulate the vortex dynamics from where new ?uxonics mechanisms can be envisaged.

In-Plane Anisotropy of Vortex Motion and Electronic State of the CuO Chain in $YBa_2Cu_3O_y$

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High-T_c superconductor $YBa_2Cu_3O_y$ shows a pronounced anisotropy in the *ab* plane due to the anisotropic crystal structure and electronic state. In order to study the in-plane anisotropy, a technique of rotating the transport current ("a vector current method") has been employed. Since the method has four electrical contacts along the *x*-direction (//*b*-axis), which are used for usual four-terminal transport measurements, are oriented 90° with respect to the other four contacts along the *y*-direction (//*a*-axis), the direction of both the transport current density *J* (~ 0.5 - 12 A/cm^2) and the vortex motion can be controlled using the two current sources. In the normal state the angular dependence of the resistivity ?(?) is described by the effective mass model. Here, ? is an angle between *J* and the *b*-axis. In magnetic fields (*H*//*c*) below T_c, ?(?) is closely
connected with the anisotropy of the vortex motion. In the vortex liquid phase with the linear resistivity, ?(?) agrees with the flux flow model which is characterized by the anisotropic viscosity ?. With decreasing temperature toward the vortex lattice melting line $T_m(H)$, ?(?) deviates from the flux flow model and the anisotropy of ?(?) is enhanced by the anisotropic pinning potential with the two-fold symmetry. In the Bragg glass phase, the vortices move only along the *b*-axis in spite of the current direction ? under constant *J*. The results indicate that the CuO chain shows an anisotropic superconductivity and works as a washboard-like potential for the vortex motion in the *ab*-plane.

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Proximity and ratchet effects in mesoscopic superconducting/magnetic systems

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Superconductivity and magnetism are well known competing long range order phenomena. New effects appear when the sample dimensions are similar to the physical scale lengths that govern these two effects.

In this talk we will address two topics. The interplay between random magnetic nanoparticles and superconducting films and the effect of ordered nanoparticle arrays on the superconducting vortex lattice dynamics. In the first example we will study the effect of different capping materials on the superconducting/magnetic proximity effects. In the second case, we will show that commensurability effects of the whole vortex lattice governs the reversible ratchet effect that appears when the vortex lattice is driven by ac input forces on ordered arrays of asymmetric pinning potentials.

Novel vortex phenomena in three-dimensional superconductor-ferromagnet hybrids

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In this presentation, we show (i) novel vortex-loop configurations inside three-dimensional mesoscopic superconducting (SC) samples (e.g. sphere, cube) with small ferromagnetic (FM) core; (ii) the dynamics of vortex loops in applied current and applied homogeneous magnetic field; (iii) the 3D aspect of the theory of magnetic vortex pinning in a SC-FM-SC sandwich; (iv) the tuning of Abrikosov vortex - antivortex pairs to Josephson vortices in the latter sample; and (v) vortex phenomena in thick SC films under a magnet with driven topology.

[*]in collaboration with M.M. Doria, A.R. de C. Romaguera (*Universidade Federal do Rio de Janeiro, Brazil*), B. Jankó (*University of Notre Dame, USA*), A. Libál (*LANL, University of Notre Dame, USA*)

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Vortex Matter in Superconducting Films with a Square Array of Anti-dots

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I will discuss the vortex physics in superconducting films containing a lattice of anti-dots. Previous theoretical treatments of this problem were limited to the London theory where vortices are modeled as classical point particles. We solved the non-linear Ginzburg-Landau equations numerically 'exact'.

New vortex configurations are found between the anti-dots: *giant-vortices*, combination of *giant- and multi-vortex* states, as well as symmetry imposed *vortex-antivortex* states for particular geometrical parameters of the sample. The anti-dot occupation number is calculated as a function of relevant parameters and compared with existing expressions for the saturation number and with experimental results. Novel behavior of the vortex anti-dot interaction is predicted for particular sizes of the anti-dot.

For small radius of the anti-dots a triangular vortex lattice can be stabilized where some of the vortices are pinned by the anti-dots and some of them are located between them. The enhanced critical current at integer and rational matching fields is found, where the level of enhancement at given magnetic field directly depends on the vortex-occupation number of the anti-dots. For certain parameters of the anti-dot lattice and/or temperature the critical current is found to be *larger* for higher magnetic fields as found recently in experiments.

Quasi-One-dimensional Vortex in Mesoscopic Superconducting Rings

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In mesoscopic superconductors with sizes comparable to the superconducting coherence length and/or penetration depth, novel superconducting states have been theoretically predicted and some of them are experimentally confirmed. For mesoscopic rings, a singly-connected superconducting state (so-called one-dimensional (1D) vortex state) has been predicted for a decade. In this state, the superconducting order parameter vanishes at a point where the phase jumps by π, when half of the flux quantum is applied to the ring, forming a structure similar to a superconducting quantum interference device (SQUID).

In this talk, we provide an experimental evidence for formation of the 1D vortex state in a superconducting ring with nonuniform line width. Here, we used the multiple-small-tunnel-junction method, in which two small tunnel junctions are attached to the narrowest and widest parts of the ring to compare the local strength of the superconductivity at these parts. We observed the continuous change of the junction voltages without hysteresis and the suppression of the superconductivity in the narrowest part for the first vortex entry/exit, which agree with the properties of the 1D vortex state. The experimental results are compared with the numerical simulation within the framework of the Ginzburg-Landau theory.

Hall micro-probe study of a few-fluxoid lead crystal

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Superconductors at the micrometer scale display several interesting phenomena related to the boundary conditions that sample surfaces impose onto a superconducting condensate. The effects of fluxoid quantization are especially pronounced since the flux quantum $f_0 = h/2e = 2.07\ \mathrm{mT}\cdot(\mu\mathrm{m})^2$ corresponds to easily accessible magnetic fields at fractions of the critical field of common low-T_c materials. Most experimental works on few-fluxoid superconductors have, however, been limited to aluminium (Al) structures in deposited films. Since such samples have a mean free path much shorter than the coherence length, the characteristic length scales depend on sample preparation and differ from their corresponding bulk values, adding complexity to the interpretation of experiments. In this work, we study an electrochemically grown, thick, micrometer-sized lead (Pb) single crystal of triangular shape with $T_c = 7.18$ K and $H_c(0) \sim 80$ mT in excellent agreement with clean, bulk Pb. This mesoscopic system allows an easy adjustment of the maximum accomodated fluxoid state by tuning the temperature. Magnetization loops were measured at various temperatures through ballistic Hall micro-probe magnetometry. Several observations are made: (i) The magnetization loops at low temperatures resemble those of bulk Pb and exhibit hysteresis, trapped flux, and the intermediate state. Discrete flux quantum changes of the magnetization are nonetheless still apparent both on flux entry and exit. (ii) Flux quantum steps are seen even above the bulk H_c, as obtained by extrapolating the intermediate state magnetization to zero, and disappear only at a higher field. (iii) The Meissner state becomes more pronounced with increasing temperature. The field of first flux entry thus approaches $H_c(T)$, with apparent loss of shape (demagnetizing) effect, indicating superheating. (iv) Close to T_c the stability of different fluxoid becomes anomalous, so that fluxoid states survive to higher fields the less flux they enclose. All these observations are preliminary explained in terms of surface superconductivity in combination with a temperature-dependent Ginzburg-Landau parameter, crossing over from $\kappa > 0.42$ for $T < T_x$ to $\kappa < 0.42$ for $T > T_x$, where $T_x \sim 6.6$ K. The stability of different fluxoid states and the transitions between them are also used to shed light on the flux structure of the type-I superconductor in the intermediate and metastable states.

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Basic Properties and applications of composite structures of d- and s-wave superconductors; d-dot

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Anisotropic superconductors show interesting properties, sometimes. In particular, the corner junction experiment shows such interesting property. It is also a key experiment for determination of the symmetry of the high-Tc superconductors. A corner junction between d- and s-wave superconductors show spontaneous magnetic flux around the right-angled corner. The total flux is a half of flux quantum $\Phi_0 = hc/2e$ [1,2]. This comes from the sign-change of the wavefunction of Cooper pairs between both sides of the corner junction around the corner. Beautiful experiments for demonstrating this property were done by Hilegenkamp et al. [3,4].

Our proposal is based on this property of the junction between d- and s-wave superconductors. If small d-wave superconductors, such as high-Tc superconductors, are embedded in a conventional s-wave superconducting matrix, then we can also expect spontaneous magnetic fluxes at the corners. How magnetic fluxes appear depends on the shape of the d-wave superconducting dot. But if such magnetic fluxes appear, then this state breaks time reversal symmetry. So, this system has doubly degenerate stable states, independent from its shape. Therefore we can treat this d-wave superconducting region a single bit as a whole. We call it a d-dot [5,6].

Analysis of behaviors of the d-dot systems has been done based on the phenomenological Ginzburg-Landau equations [5-7]. To take into account anisotropy of the d-wave superconductivity, we use a two-components GL equation [8]. Using the finite element method, we successfully reproduce the spontaneous magnetic fluxes for a corner junction and for other geometries. Their response to an external field and an external current was also studied.

For the application of d-dot systems, the interaction between d-dot's is important. We investigated two-body interaction of d-dot's, obtaining the stable configuration of two d-dot's [9]. The results show that the interaction depends on the direction and distance and that it changes from ferromagnetic to anti-ferromagnetic. If the size of d-dot's becomes small compared to the Josephson penetration depth, they behave as a quantum bit [10]. So they are also candidates of qubits. I will discuss further applications of d-dot's.

[1] D. J. Van Harlingen, Rev. Mod. Phys. 67 (1995) 515.
[2] C. C. Tsuei and J. R. Kirtley, Rev. Mod. Phys. 72 (2000) 969.
[3] H. Hilgenkamp, Ariando, H-J. H. Smilde, D. H. A. Blank, G. Rijnders, H. Rogalla, J. R. Kirtley, and C. C. Tsuei, Nature **422** (2003) 50.
[4] J. R. Kirtley, C. C. Tsuei, A. Ariando, C. J. M. Verwijs, S. Harkema, H. Hilgenkamp, Nature Phys. **2** (2006) 190.
[5] M. Kato, M. Ako, M. Machida, T. Koyama, T. Ishida, Physica C **412– 414** (2004) 352.
[6] M. Kato, M. Ako, M. Machida, T. Koyama, and T.Ishida, J. Mag. Mag. Mat. 272-276 (2004) 171.
[7] M. Ako, M. Machida, T. Koyama, T. Ishida, M. Kato, Physica C **412– 414** (2004) 544.
[8] Y. Ren, J-H. Xu, and C. S. Ting, Phys. Rev. Lett. **74**, 3680 (1995).
[9] M. Hirayama, M. Machida, T. Koyama, T. Ishida and M. Kato, Physica C, **426-431** (2005) 127.
[10] T. Koyama, M. Machida, M. Kato and T. Ishida, Physica C, 426-431 (2005) pp. 1561-1565.

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Abstracts of Poster Presentations

P1

Effect of Columnar Disorder on the Vortex Matter Phase Diagram in Untwinned $YBa_2Cu_3O_y$

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In order to study effects of columnar disorder on the vortex phase diagram, we have measured resistivity ?(H, T) and magnetization $M(H)$ up to 15T in heavy ion irradiated untwined $YBa_2Cu_3O_y$ single crystals. The irradiation dose was B_F = 0, 0.1, 0.5, 1.0 and 2.0 T. With increasing B_F, the first-order vortex lattice melting transition $H_m(T)$ is suppressed near the upper and lower critical points (H_{ucp} and H_{lcp}) and the resistive transition shows a broad temperature dependence, indicating the second-order transition. We find that the first-order melting transition completely disappears when the irradiation dose has a value of 0.5 T < B_F < 1.0 T and the transition becomes the second-order Bose glass transition when B_F >1.0 T. For B_F = 0.5 T, the first-order melting transition exists in the very narrow field region above H_{lcp} = 4.5 T and below H_{ucp} = 10 T without any characteristic features such as the field-driven order-disorder transition $H^*(T)$ line in the vortex solid phase. The result implies that the vortex liquid freeze into the Bose glass phase through the first-order transition in case of weak columnar disorder. In the vortex solid phase for B_F = 0 and 0.1 T, the $M(H)$ curve shows the clear step structure at the onset of the second peak, indicating the order-disorder transition at $H^*(T)$. The existence of the $H^*(T)$ line for B_F = 0.1 T suggests the transition from the ordered vortex phase (i.e., Bragg-Bose glass phase) into the Bose glass phase.

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P2

Scanning Tunneling Microscopy/Spectroscopy on Superconducting Boron-Doped Diamond

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We have performed scanning tunneling microscopy/spectroscopy (STM/STS) experiments on thin films of heavily boron-doped diamond. The (111)-oriented epitaxial films (T_c = 5.4 K) were grown by using the microwave plasma-assisted chemical vapor deposition method. STM/STS measurements were performed by ^{3}He-refrigerator based STM under ultra-high vacuum. The tunneling junctions were made between (111)-surface of boron-doped diamond thin films and mechanically sharpened PtIr tips. The STM topography on the film surface shows a corrugation (with a typical size of ~ 1 μ m) and grain-like microstructures (~ 5 - 20 nm). In the low temperature region (T ~ 0.47 K), the tunneling conductance spectra do not show large spatial dependence and superconductivity is observed independent of the surface structures. The tunneling spectra are analyzed by the Dynes function and the superconducting energy gap is estimated to be ? = 0.87 meV at T = 0.47 K, corresponding to 2? /kBT_c = 3.7. The relatively large value of the broadening parameter G = 0.38 meV is discussed in terms of the inelastic electron scattering processes. In the high temperature region (T ~ 4.2 K), on the other hand, the tunneling conductance spectra show large spatial dependence, indicating the inhomogenious distribution of the superconducting property, which may result from the distribution of boron atoms.

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P3

Magnetic Resonance Studies on $RuSr_2GdCu_2O_8$

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We performed microwave resonance experiments on crystals of $RuSr_2GdCu_2O_8$. Using a home built spectrometer, measurements were done at 22GHz and 32GHz with the static magnetic field, H_s, perpendicular and parallel to the rf magnetic field, H_{rf}. This arrangement allows us to measure surface resistance and resonance of any magnetic ions.
Our primary results are:

1. Below T_c flux flow resistivity is observed in both field configurations.

2. A Gd resonance is observed in both resonance and non-resonance configurations of H_s. If Gd orders antifer-romagnetically at 2.5 K, as reported in literature, no Gd resonance should be detected above T_N for $H_s \parallel H_{rf}$

3. A Ru resonance is observed, below T 160 K, in both configurations. This indicates that the Ru is ordered either antiferromagnetically or weak-ferromagnetically with a transition temperature, T_N 160 K.

P4

Magnetic Field Dependence of the Lock-in Transition in $Bi_2Sr_2CaCu_2O_{8+d}$ Mesoscopic Single Crystals

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We have investigated lock-in transition phenomena from crossing lattice state to Josephson vortex state, which occurs very sharply like the first order transition in the mesoscopic intrinsic Josephson junctions of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) single crystals. We have measured angular dependence of the *c*-axis resistivity as functions of magnetic fields, *c*-axis currents, and temperatures. In the lock-in state, JV's easily flow along the *ab*-plane due to Lorentz force exerted by the *c*-axis current, resulting in appearance of the JV flow resistance along the *c*-axis. By tilting magnetic field from the *ab*-plane, a sudden drop of the *c*-axis resistance is observed at *q*?$_{\mathrm{LI}}$ measured from the *ab*-plane, which strongly depends on temperature, applied magnetic field, and the junction size. This sudden drop of the resistivity is a signature to the transition to the crossing lattice state, where JV flow is considered to be highly impeded by the attractive interaction with pancake vortices. The *c*-axis component of the applied magnetic field at the transition angle is regarded as the first penetration field of pancake vortices, namely $H_{\mathrm{pn}} = H\sin q$?$_{\mathrm{LI}}$. It was found that H_{pn} decreased with increasing magnetic field parallel to the *ab*-plane H_{ab} up to about 2 T. Furthermore, in $H_{ab} > 2$ T, the lock-in transition is considerably broadened and H_{pn} begins to depend on the bias currents. These results can at least be explained qualitatively by considering the screening current induced by the Josephson vortices.

P5

Superconducting Qubits

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This poster overviews our theoretical studies (some done with J.S. Tsai and Y. Nakamura) on superconducting (SC) circuits and quantum information (see, e.g., Phys. Today 58(11), 42 (2005)) including:

- SC qubits coupled and addressed as trapped ions (condmat/ 0509236)
- Controllable coupling between flux qubits (PRL 96, 067003 (2006))
- Hybridized solid-state qubit in the charge-flux regime (PRB 73, 014510 (2006))
- Testing Bell's inequality in constantly coupled SC qubits (PRB 72, 104516 (2005)) Quantum computation with SC qubits by using a current-biased information, PRB 71, 134506 (2005)
- Tomographic measurements on SC qubit states, PRB 72, 014547 (2005)
- Preparation of macroscopic quantum superposition states of a cavity field via coupling to a SC charge qubit, PRA 71, 063820 (2005)
- Coupling Josephson qubits via a current-biased information bus (EPL 67, 1004 (2004))
- Generation of nonclassical photon states using a SC qubit in a microcavity (EPL 67, 941-947 (2004))
- Fast two-bit operations in inductively coupled flux qubits, (PRB 71, 024532 (2005))
- Controllable manipulation and entanglement of macroscopic quantum states in coupled charge qubits, (PRB 68, 024510 (2003))
- Scalable quantum computing with SC charge qubits; PRL 89, 197902 (2002); and quantum information processing with SC qubits in a microwave field (PRB 68, 064509 (2003))

P6

Magnetic and Mechanical Buckling: Moified Landau Theory Approach to Study Phase Transitions in Micro-magnetic Disks and Compressed Rods

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Using the rigid magnetic vortex model, we develop a substantially modified Landau theory approach [1] for analytically studying phase transitions between different spin arrangements in circular sub-micron magnetic dots subject to an in-plane externally-applied magnetic field. We introduce a novel order parameter: the inverse distance between the center of the circular dot and the vortex core. This order parameter is suitable for describing closed spin configurations such as curved or bent-spin structures and magnetic vortices. Depending on the radius and thickness of the dot as well as the exchange coupling, there are five different regimes for the magnetization reversal process when decreasing the in-plane magnetic field. The magnetization-reversal regimes obtained here cover practically all possible magnetization reversal processes. Moreover, we have derived the change of the dynamical response of the spins near the phase transitions and obtained a "critical slowing down" at the second order phase transition from the high-field parallel-spin state to the curved (C-shaped) spin phase. We predict a transition between the vortex and the parallel-spin state by quickly changing the magnetic field --- providing the possibility to control the magnetic state of dots by changing either the value of the external magnetic field and/or its sweep rate. We study [1] an illuminating mechanical analog (buckling instability) of the transition between the parallel-spin state and the curved spin state (i.e., a magnetic buckling transition). In analogy to the magnetic-disk case, we also develop a modified Landau theory for studying mechanical buckling instabilities of a compressed elastic rod embedded in an elastic medium. We show that the transition to a buckled state can be either first or second order depending on the ratio of the elasticity of the rod and the elasticity of the external medium. We derive the critical slowing down for the second-order mechanical buckling transition. Using our analytical approach to mechanical buckling, we proposed a nanomechanical qubits [2] which can be made of suspended nano tube.

[1] S. Savel’ev and F. Nori, Phys. Rev. B 70, 214415 (2004)
[2] S. Savel’ev, X.D. Hu, and F. Nori, New J. Phys. 8, 105 (2006).

P7

Controlling the Motion of Tiny Particles and Magnetic Flux Quanta

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New types of nanodevices have recently been proposed for particle motion control [1-6], including particle separation, and superconducting vortex manipulation. If small particles are driven by an ac external force (or by a fluctuating force) on an asymmetric substrate, their ac motion can be rectified, thus providing useful work. Some of these devices have been realized experimentally to manipulate vortices, particles in asymmetric silicon pores, as well as charged particles through artificial pores and arrays of optical tweezers. We have proposed several novel approaches to control motion of small particles. We studied [1-3] the collective stochastic rectification of ac-driven vortices due to the "ratchet effect" produced by asymmetric pinning sites. The regular structure studied can produce a dc voltage from ac driven vortices. For instance, using two interpenetrating square pinning sublattices allows a precise control of the collective motion of the vortices, including step-motors. We numerically obtained magnetic "lensing" of fluxons.
Moreover, we also have studied [4-6] motion control without any spatially asymmetric potential (i.e., no ratchet).

[1] B.Y. Zhu, F. Marchesoni, V.V. Moshchalkov, F. Nori, *Phys. Rev. B* 68, 014514 (2003). This proposal motivated experiments at Leuven (PRL and Nature). F. Nori, *Nature Physics* (April 2006).
[2] J.E. Villegas, S. Savel'ev, F. Nori, E.M. Gonzalez, J.V. Anguita, R. García, J.L. Vicent, *Science* 302, 1188 (Nov. 14, 2003); see also "Enhanced Perspectives" in *Science* 302, 1159, by H. Hilgenkamp, V. V. Moshchalkov, P. Kes.
[3] B.Y. Zhu, F. Marchesoni, F. Nori, *Phys. Rev. Lett.* 92, 180602 (2004).
[4] S. Savel'ev, F. Marchesoni, F. Nori, *Phys. Rev. Lett.* 91, 010601 (2003); *Phys. Rev. Lett.* 92, 010601 (2004); *Phys. Rev. E* 70, 061107 (2004); *Phys. Rev. E* 71, 011107 (2005).
[5] S. Savel'ev, F. Nori, *Nature Materials* 1, 179 (2002), See also the companion "News and Views" by G. D'Anna.
[6] D. Cole, S. Bending, S. Savel'ev, A. Grigorenko, T. Tamegai, F. Nori, *Nature Materials* (April 2006). See also the News and Views by A. Tonomura, in the same issue.

P8

Surface THz Plasma Waves and THz Detectors

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We predict [1] the existence of surface waves in layered superconductors in the THz frequency range below the plasma frequency. This wave propagates along the vacuum-superconductor interface and dampens in both transverse directions out of the surface (i.e., towards the superconductor and towards the vacuum). The predicted surface Josephson plasma waves are important for different phenomena, including the effect of complete suppression of the specular reflection from a sample (Wood's anomalies) and for a huge enhancement of wave absorption (which can be used as a THz detector).

[1] S. Savel’ev, V. Yampol’skii, and F. Nori, Phys. Rev. Lett. 95, 187002 (2005)

P9

THz Radiation Generation and Control Using Superconductors

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• *Generation of tunable terahertz out-of-plane radiation using Josephson vortices in modulated layered superconductors:*
We show [1] that a moving Josephson vortex in spatially modulated layered superconductors generates out-of-plane THz radiation. Remarkably, the magnetic and in-plane electric fields radiated are of the same order, which is very unusual for any good-conducting medium. Therefore, the out-of-plane radiation can be emitted to the vacuum without the standard impedance mismatch problem. Thus, the proposed tunable THz emitter for out-of-plane radiation can be more efficient than the standard one which radiates only along the *ab*-plane.
• *Using Josephson Vortex Lattices to Control Terahertz Radiation:*
Tunable Transparency and Terahertz Photonic Crystals:
The Josephson vortex (JV) lattice is a periodic array that scatters electromagnetic waves in the THz-frequency range. We show [2] that JV lattices can produce a photonic band-gap structure (THz photonic crystal) with easily tunable forbidden zones controlled by the in-plane magnetic field. The scattering of electromagnetic waves by JVs results in a strong magnetic-field dependence of the reflection and transparency. Fully transparent or fully reflected frequency windows can be conveniently tuned by the in-plane magnetic field. These proposals are potentially useful for controllable THz filters.
• *Surface Josephson plasma waves in layered superconductors:*
We predict [3] the existence of surface waves in layered superconductors in the THz frequency range, below the Josephson plasma frequency omega_J. This wave propagates along the vacuum-superconductor interface and dampens in both transverse directions out of the surface (i.e., towards the superconductor and towards the vacuum). This is the first prediction of propagating surface waves in any superconductor. These predicted surface Josephson plasma waves are important for different phenomena, including the complete suppression of the specular reflection from a sample (Wood's anomalies) and a huge enhancement of the wave absorption (which can be used as a THz detector).
• *Analogues of nonlinear optics using terahertz Josephson plasma waves in layered superconductors:*
Josephson plasma waves (JPWs) can propagate in the terahertz (THz) range, which is important for applications. However, *nonlinear* JPWs have not yet been studied. It is a challenge to understand nonlinearities around the plasma frequency, where the interplay between the unusual spectrum and the nonlinearity of the JPWs is most pronounced. In analogy to nonlinear optics, we [4] predict that these nonlinear JPWs exhibit numerous remarkable features, including the slowing down of light (when the group velocity is close to 0), self-focusing effects and the pumping of weaker waves by stronger ones. Their nonlinearity can potentially be used for transforming continuous THz radiation into amplified pulses.

[1] S. Savel'ev, V. Yampol'skii, A.L. Rakhmanov, and F. Nori, *Phys. Rev. B* 72, 144515 (2005).
[2] S. Savel'ev, A. L. Rakhmanov, and F. Nori, *Phys. Rev. Lett*. 94, 157004 (2005).
[3] S. Savel'ev, V. Yampol'skii, and F. Nori, *Phys. Rev. Lett.* (October 2005).
[4] S. Savel’ev, A.L. Rakhmanov, V.A. Yampol’ski, and F. Nori, *Nat. Phys.* (August 2006).

P10

Enhancing critical Currents in Superconductors with Quasiperiodic Pinning Arrays: Chains and Two-dimensional Penrose Lattices.

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We study the critical depinning current *Jc*, as a function of the applied magnetic flux, for quasiperiodic (QP) pinning arrays, including quasi-onedimensional (1D) chains and two-dimensional (2D) arrays of pinning centers placed on the nodes of a fivefold Penrose lattice. In 1D QP chains of pinning sites, the peaks in *Jc* are shown to be determined by a sequence of harmonics of long and short periods of the chain. This sequence includes as a subset the sequence of successive Fibonacci numbers. We also analyze the evolution of *Jc* while a continuous transition occurs from a periodic lattice of pinning centers to a QP one; the continuous transition is achieved by varying the ratio=*aS* /*aL* of lengths of the short *aS* and the long *aL* segments, starting from=1 for a periodic sequence. We find that the peaks related to the Fibonacci sequence are most pronounced when is equal to the "golden mean." The critical current *Jc* in a QP lattice has a remarkable self-similarity. This effect is demonstrated both in real space and in reciprocal *k* space. In 2D QP pinning arrays e.g., Penrose lattices, the pinning of vortices is related to matching conditions between the vortex lattice and the QP lattice of pinning centers. Although more subtle to analyze than in 1D pinning chains, the structure in *Jc* is determined by the presence of two different kinds of elements forming the 2D QP lattice. Indeed, we predict analytically and numerically the main features of *Jc* for Penrose lattices. Comparing the *Jc*'s for QP Penrose, periodic-triangular and random arrays of pinning sites, we have found that the QP lattice provides an unusually broad critical current *Jc*, that could be useful for practical applications demanding high *Jc*'s over a wide range of fields.

V. Misko, S. Savel'ev, and F. Nori, *Phys. Rev. Lett.* 95, 177007 (2005); *Phys. Rev. B* (August 2005).
This work has motivated several experiments(e.g., UCSD, Tuebingen, Leuven).

P11

Thermodynamic Phase Diagram of Interlayer Josephson Vortices

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The thermodynamic phase diagram of interlayer Josephson vortices will be discussed. First we show the magnetic field dependence of zero-temperature vortex lattice configuration, which is nontrivial because of the competition between the intervortex repulsion and the underlying layered structure of cuprates [1]. It is then revealed by means of the density functional theory that a smectic phase with long-range c-axis density modulation of period 2s and short-range intralayer vortex correlation can be stabilized by sufficiently strong layer pinning such as in YBCO at appropriate magnetic field and intermediate temperature [2]. At strong magnetic field, a Kosterlitz-Thouless phase appears, which is characterized by short-range vortex correlation in c-axis and quasi-long-range in-plane correlation and accessible in BSCCO [3]. This phase possesses a vanishing interlayer shear modulus, and thus relative slides of the Josephson vortex sheets take place without cost of free energy. It is found by dynamics simulation that in this phase dissipation caused by in-plane current does not depend on the angle between current and magnetic field [4].

This paper is based on the collaborations with M. Tachiki, Q.-H. Chen, M.-B. Luo, and Y. Nonomura.

References:
[1] Y. Nonomura and X. Hu, Phys. Rev. B, **74**, 024504 (2006); See also talk by A. Koshelev.
[2] X. Hu, M.-B. Luo, and Y.-Q. Ma, Phys. Rev. B, **72**, 174503 (2005).
[3] X. Hu and M. Tachiki, Phys. Rev. B, vol. 70, 064506 (2004); *ibid*. Phys. Rev. Lett. **85**, 2577 (2000); *ibid.* **85**, 2577 (1998).
[4] Q.-H. Chen and X. Hu, preprint.

P12

Fabricating superconducting nanostructures using anodic aluminum oxide: a versatile template approach

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Nanostructures including nanowires, nanotubes, nanoscale dots and antidots are promising subjects for studying novel phenomena in confined geometries and have potential applications in devices. It is challenging to fabricate nanostructures in a controlled way and new techniques are continually being developed. One versatile approach is the 'template synthesis' that utilizes nanopores in porous membranes as templates. In this poster we will introduce electro-chemical anodization procedures for synthesizing a new generation of membranes – anodic aluminium oxide (AAO) membranes – that contain large-area periodic arrays of uniform nanochannels. By electrodepositing Pb into the nanochannels we fabricated superconducting nanowires. Superconducting Nb films containing arrays of holes with diameters down to a few nanometers have also been achieved by using AAO membranes as substrates. These nanostructures were characterized with scanning electron microscopy, magnetization and transport measurements. Detailed information on fabrication approaches and characterization of the AAO membranes and superconducting nanostructures will be presented in this poster.

P13

3D Mesoscopic Superconductors with Controlled Shapes

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Properties of a superconducting sample are strongly influenced by its shape when its size is comparable to fundamental superconducting length scales, i.e. the superconducting coherence length and penetration depth. Recent experiments and theories have demonstrated plenty of novel phenomena in the 2D mesostructures. In 3D superconducting mesostructures, however, physics is largely unknown. The main obstacle to pursue the physics in 3D mesostructures is the difficulty in synthesizing the samples. Recently, we found that mesoscopic superconductors with well-defined one-, two- and three dimensional shapes can self-assemble onto flat surfaces by strictly controlling particular electrodeposition conditions. In addition to wires, triangular hexagonal samples, 3D shapes such as pyramids, pentagons, and brushes were obtained for superconducting lead (Pb) samples. These shapes are hardly achievable through conventional e-beam lithography and provide us unique opportunities to delve into new fascinating phenomena associated with shape-effect at the mesoscale. Detailed information on synthesis and characterization of Pb mesocrystals will be presented in this poster.

P14

Phase diagram difference in ion-irradiated YBCO by heat capacity measurements

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We study the evolution of the vortex phase diagram of $YBa_2Cu_3O_{7-d}$ upon the introduction of correlated defects using specific heat measurements. The heat capacity of crystals with less than 1μg mass is determined in a differential ac-calorimeter based on Si_3N_4-membranes. In pristine $YBa_2Cu_3O_{7-d}$ crystals, the applied magnetic field penetrates into the crystal and forms the Abrikosov vortex lattice structure with triangular symmetry. At higher temperature the vortex lattice melts into a vortex liquid state via a first order phase transition as evidenced by a sharp peak in the specific heat. The introduction of defects tends to destroy the vortex lattice and leads to the creation of a disordered glassy vortex state which melts via a higher order continuous transition. In this ongoing study, we perturb the vortex melting transition by introducing columnar defects via high-energy heavy ion irradiation. Pristine YBCO crystals with first order melting transitions were irradiated along the crystallographic c-axis with 1.4 GeV Pb ions to a dose matching field of B_Φ=0.1T. The lower critical point was found to shift upward after irradiation as predicted. A thermodynamic signature of the Bose Glass state was observed as a discontinuous step in the specific heat. Furthermore, the first order vortex melting transition was recovered by tilting the magnetic field away from the axis of the irradiation.
Future work will focus on thermodynamically determining the threshold of defects necessary to transform a first order transition into a continuous transition.

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P15

Report of the Basic Energy Sciences (BES) Workshop on BASIC RESEARH NEEDS FOR SUPERCONDUCTIVITY

On May 8-11, 2006, the U.S. Department of Energy's Office of Basic Energy Sciences (BES) held a Workshop on Basic Research Needs for Superconductivity to examine basic research needs and opportunities in superconductivity with a focus on new, emerging and scientifically challenging areas that have the potential to have significant impact in science and energy relevant technologies.

Superconductivity is on the verge of creating historic transformational opportunities for technology and science. These opportunities offer four grand challenges that, if met, would open new frontiers for the science of superconductivity and complex materials and help transform the capacity, reliability, and efficiency of the electric power grid. The four grand challenges encompass discovery and use-inspired research and share many of the same innovative pathways in their pursuit of the ultimate goals: knowledge and understanding for science and performance and functionality for technology. In the spirit of Pasteur, the synergistic pursuit of all four goals is enormously more productive than pursuing any one alone.

The poster highlights the grand challenges and the priority research directions identified in the BES Workshop

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